# “It's not just old jokes that get recycled.”
# Science communication and entertainment in *The Cartoon Introduction to Climate Change*

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## 1. Introduction

For many of us, studying by reading blocks after blocks of text can be tedious and far from enjoyable. For me, it is. I find it frustrating and time-consuming that in order to learn – be it chemistry, history, or literary theories, formally or casually – I have to read whole books with linear black-on-white text, very often unillustrated and unattractive. All too often, it takes extra effort to find the point the writer was trying to explain. Then I have to translate the theory into a form I find the easiest to learn and memorize from, i.e. mindmaps, graphs, and illustrations of my own. All this hassle makes me think, "there must be a better way to do this!" And, as it appears, there is; fortunately, many researchers, science communicators, and educators acknowledge that simply reading linear text is not always the most efficient way to teach and learn and have turned to comics and graphic novels as educational tools.

Comics have many uses in communication. In language studies, comics are often used to demonstrate the flow of discussion and correct phrases, and in research of conversation and interaction, comics can be used to illustrate the order and direction of gestures and turns of speech, for example. In medicine, illustrations have been used for a long time for demonstration purposes (Shurkin, 2015). They are useful when teaching the general public about a specific subject such as global warming (Tribull, 2017). Also, manuals, for example, are often in comic form (Tatalovic, 2009). Educational and informational comics span a wide range of topics and subjects, and they are not uniform in their way of communicating their content; some contain complex narratives while others simply state the facts. These comics, especially the ones that deal with subjects relating to natural sciences, are often called science comics or even non-fiction science comics to distinguish them from other kinds of comics (Tatalovic, 2009). However, the distinction is not always straightforward: because some science comics do use fiction as a part of their narration, Tatalovic (2009) prefers the term science comics to non-fiction science comics when referring to comics whose main purpose is to educate the reader. Furthermore, it should be noted that scientific accuracy is not an exclusive quality of science comics – references to scientific ideas and facts can also be found in non-educational comics (Tatalovic, 2009). Thus, in order to keep the terminology consistent and to define the scope of this study, I will use the term **science comics**. I will also consider only comics that have been made exclusively for educational or communicational purposes.

In this study, I will address the following questions:

1) How is science content presented in and adapted into comic form?

2) How has the comic been designed to make learning and reading entertaining? More specifically, what are the ways through which the comic entertains the reader?

To answer these questions, I will analyse the comic book *The Cartoon Introduction to Climate Change* by Yoram Bauman, PhD. and Grady Klein. In an attempt to approach the questions from multiple angles, I will also include an ethnographic dimension to the study by interviewing a science comic artist about the process of making a science comic. These complementary approaches will be used to gain a broad understanding of the phenomenon. Moreover, the triangulation of data and methods aids at the validation of findings.

In addition to my frustrating experiences with linear texts, I have another motive for my research: as a comic artist, I want to learn and provide knowledge of how comics can be used to improve learners' interest to study and learn about science. I see communication as the core of our human lives: we communicate with other humans, whether we want it or not – choosing to stay silent is also an act of communication –, and communication may determine our successes and failures, both individual and communal. Through studying comics, I can combine my Graphic Design studies of visual communication, English Philology studies of written communication, and my comics creator ”jobby” where words, images, and the psychology of communication become entwined. My experience regarding educational comics in the field of natural sciences is limited to occasional excerpts in school science classes and random encounters with science-related comic strips online. However, comics such as those by Liv Strömquist's that refer to actual research in social sciences have expanded my understanding of human behaviour, and Alison Bechdel's *Are You My Mother?*, an autobiographical comic about Bechdel's complex relationship with her mother, introduced me to new theories of psychology. Also, the comic *Fullmetal Alchemist* by Hiromu Arakawa made me want to learn more about chemistry when I was a teen. The world of *Fullmetal Alchemist* is purely fictional but its magic-like alchemy is based on chemistry. Intrigued by the way minuscule particles and chemical reactions affect our world every moment of our lives, I studied advanced chemistry in high school. I did not become a chemist but my real-life example alone is a proof of the inspirational power that well-presented science has on people.

Thus, the aim of this study is also to explore how to present science in comics and find the ways in which to inspire comic readers to become interested in science. The next section will investigate the history and role of comics and science comics in, especially, the Western culture. I will also examine earlier research regarding science comics.

## 2. Previous research on key concepts

First, it is necessary to define the key concepts of this study and explain how they are connected to the topic and how I use them to answer the research questions. The key concepts that form the basis of analysis are science comics, science communication, autonomous learning, and entertainment.

### 2.1 On science comics

In this section, I will define the concept of science comics; moreover, I will discuss the history of comics and science comics and the credibility of science comics in education and communication. Then, I will present results from case and experimental studies regarding the use of science comics in education and communication.

#### 2.1.1 Briefly about the history and credibility of science comics

McCloud's (1994) definition of comics is ”juxtaposed pictorial and other images in deliberate sequence, intended to convey information and/or to produce an aesthetic response in the viewer” (p. 9). This means that single panels, even with text and speech balloons, are not comics but cartoons (McCloud, 1994). McCloud (1994) also emphasizes the importance of intention, both in the arrangement of images and communicational purposes, in the creation of a comic. McDermott, Partridge and Bromberg (2018) define comics in a different way: for them, a comic is ”generally an illustration that employs metaphor and/or storytelling to clearly communicate an idea to a broad audience” (p. 1). The latter, looser definition may be better suited for the world of science comics where even single-panel illustrations are often referred to as comics.[1] However, as the purpose and focus of this study is to examine works that feature sequences of images and that have been created for communicational purposes, McCloud's definition suffices.

When McCloud's definition – comics are juxtaposed images in a delibereate sequence – is kept in mind, the history of visual arts is littered with comics. Examples of early comics are Egyptian paintings from 1300 BC, a pre-Columbian picture manuscript discovered by Spanish conquerors around 1519, and the Bayeux Tapestry from the Middle Ages (McCloud, 1994). The discovery of printing was as important a milestone for comics as it was for the written word: thanks to decreased production costs, comics became cheaper and affordable for a broader audience

1 The definition may also feel less intimidating to scientists who wish to draw their own comics and may create less pressure for them.

(McCloud, 1994). Picture stories, such as William Hogarth's *A Harlot's Progress* from 1731 became so popular that new copyright laws had to be created to protect the original author's rights (McCloud, 1994). However, these picture stories consisted only of sequential art and contained no words, and the foundation for the comics as we know them today was laid in the mid-1800s by Rodolphe Töpffer: he was the first one in Europe to use cartooning and panel borders and to combine words into pictures (McCloud, 1994). His innovations make him the father of the modern comic (McCloud, 1994). However the first works to be called "comics" were the humorous, energetic newspaper cartoons of the 1890s; the term emphasizes their nature as diversion and entertainment (Humphrey, 2014).

Indeed, even nowadays, many people think that "comics" refers exclusively to the brightly coloured comic books featuring iconic fantasy characters, such as superheroes and Disney characters, and they are often deemed as mere amusement and very unserious. However, even though comics have been celebrated, embraced, and researched by fans during the past century (Humphrey, 2014), comics have had the reputation of bad entertainment since the birth of big comic business (Syma & Weiner, 2013). Comics were attacked vigorously by a psychiatrist called Fredric Wertham in the United States in the 1950s: in his book *The Seduction of the Innocent*, he claimed that comics are corrupting the minds of adolescents with their violent and sexual themes, and he was successful in turning the general populace against comics (Humphrey, 2014). A a consequence, in the 20th century, the word "comics" has had such negative connotations and its definition has been so narrow that many works of art that are read like comics have been deliberately excluded from the history and genre of comics – namely, the historical paintings and manuscripts mentioned above (McCloud, 1994). Even nowadays, comic books are sometimes called "graphic novels" in order to elevate their status and to discern the product from popular culture; accordingly, the term "graphic novel" is mostly used in literary awards, literary reviews in newspapers, and university libraries (Humphrey, 2014).

In the United States, educational and instructional comics are not a new phenomenon. Comics have been used for education since the 1940s, and their impact on learning has been studied almost as long (Syma & Weiner, 2013). Moreover, "since the 1950s [- -] US government bodies have been commissioning comic books to teach adults and children about topics including fire safety, civil defence", and "government educational and propaganda material" (Humphrey, 2014, pp. 76–77). In fact, *PS Monthly*, a magazine published by the US Army, was founded in 1951, and is still "one of the longest-running comic publications in the United States" (Humphrey, 2014, p. 77). For two decades, it was edited and contributed to by Will Eisner, who was also one of the first comic

creators to publish book-length comics in the US (Humphrey, 2014), so the publication did not lack credibility. Nowadays, the amount of educational comics published and available in the US is increasing, both thanks to the elevated status of comics in literary circles and the long history of educational comics (Humphrey, 2014). For instance, *Marx for Beginners* (published in English in 1976) by Rius was an instant success as were Larry Gonick's *Cartoon History of the Universe*-books that were published in the late 1980s (Humphrey, 2014). Scott McCloud's *Understanding Comics* (1993) is an educational comic about comics. Manuals have often been drawn as comics (Tatalovic, 2009), and using comics to communicate health education to patients and their families is especially common and popular (Jee & Anggoro, 2012). In addition to these educational comics intended for the general public and for autonomous learning, there are academic journal articles in comic form made by scientists and researchers themselves. Including comics in scientific papers makes research more accessible to a broader audience (McDermott, Partridge & Bromberg, 2018), for instance the general public and professionals from other relevant fields. Also, some researchers say that working with both images and text instead of only text improves their thinking (Humphrey, 2014).

In Japan, educational comics have an even stronger foothold, and they are widely used to help students excel in their studies (Itō, 2010). The schooling system in Japan is very competitive, and entrance examinations, for instance to universities, are difficult to pass (Itō, 2010). Japanese educators and the government acknowledge that the Japanese society is polarizing: intelligent students do very well at school and benefit the most from their education, later becoming part of the elite, while poor students lag behind, and finding employment may be challenging for them later in life (Itō, 2010). Textbooks with illustrations and comics have been developed to help improve the learning results of the students and pupils who face difficulties in learning from traditional textbooks and to increase their curiosity in school subjects (Itō, 2010). Educational comics intended for children are called g*akushu manga*, literally 'study comics' (Itō, 2010). Also, there are educational and informational comics for adults; these are called *kyoyo manga* (Itō, 2010). *Manga* is the Japanese word for all kinds of comics and cartoons, and *manga* is present in all fields of the Japanese life – hospitals, the government, political parties, and insurance companies, for example, use comics and drawings to educate and inform the public (Itō, 2010).

As was mentioned earlier, in the United States, comics were a shunned artform during the 20th century. In the academic world, comics have also been despised or ignored (Humphrey, 2014). Tatalovic (2009) assumes that the reasons for this are their reputation as children's entertainment and their status as a product of popular culture. McCloud (1994) surmises that combinations of

verbal text and images are inherently regarded as commercial and low-status products. He also claims that pictures are often regarded as an acceptable reading-aid for children, but when growing into adolescensce and adulthood, children are expected to gradually abandon picture books and learn to read "real" literature, i.e. books with linear verbal text only (McCloud, 1994). However, today, science comics have found their way to "classrooms, libraries, and other educational contexts", and they have been included in some state curriculums in the United States, for example (Jee & Anggoro, 2012, p. 197). Plenty of research has been conducted on comics in science communication and education. Some of the papers are straightforward guides to making science comics (e.g. McDermott, Partridge & Bromberg, 2018) while others strive to understand and explain comics as an educational and learning tool (e.g. Jee & Anggoro, 2012). In addition, many books and papers (e.g. Tribull 2017) catalogue examples of the most successful comics, be they printed or online. Tatalovic (2009) has compiled an extensive catalogue of different variations of science comics, ranging from Indian cartoon-style Scientoons to online strip-comics and comic book series. The history of educational and science comics has been comprehensively mapped as well (e.g. Syma & Weiner, 2013).

Jee and Anggoro (2012) have researched the cognitive impacts of science comics and point out that learners may benefit from perceptual experiences when studying science because "when bringing a concept to mind or forming a mental representation of an object or scene, perceptual and motor knowledge becomes activated in the mind" (p. 199). Therefore, visualizations in comics can act as substitutes to scientific objects and real-life perceptual experiences (Jee & Anggoro, 2012) – by seeing an object or event in a comic, a reader can imagine experiencing them themselves. This notion corresponds with the constructivist approach to learning and the science communication theories that I will discuss later in this study: learners need real-life contexts to which they can link abstract scientific theories. Many of these contexts can be produced in traditional classrooms, such as making students construct molecular models from building blocks made specifically for that purpose or showing how electric charge makes one's hair stick to a balloon. However, sometimes it is impossible to provide these perceptual experiences, such as when studying microscale processes of chemistry or macroscale processes of astronomy (Jee & Anggoro, 2012). This is when comics become useful: in comics, it is easy to illustrate shifts in scale by zooming in in one panel and zooming out in the next, for example (McCloud, 1994; see also Jee & Angorro, 2012). Moreover, comics have the ability to manipulate time. This is useful when showing either very slow or very fast processes and reactions. Time can be slowed down or sped up: a single panel can contain several temporally sequential events or time may appear frozen in a panel, characters can move very

fast in a panel or they may stand completely still (McCloud, 1994). Transitions from panel to panel signify movement in time and space, and these transitions can occur from moment, action, subject, scene, or aspect to another (for more detailed discussion, see McCloud, 1994).

Some problems arise when studying the effectiveness of science comics. It is not known who exactly reads science comics and for what purposes (Tatalovic, 2009). Tatalovic (2009) and Tribull (2017) note that sample sizes in the studies are very small; moreover, Tribull mentions that such studies often lack a control group. Therefore, when studying science comics' effects on learning, the results are often indicative at best and not directly applicable to larger populations. In addition, it is unfortunately still unclear whether pupils and students learn more from science comics because of the effectiveness of the medium or whether a diversion from classroom routines makes students more interested in the subject (Shurkin, 2015; Tatalovic, 2009). Another problem is the false sense of understanding readers get from science comics. If a comic is easy to read and the narration easy to understand, it may make the reader mistakenly assume that they have understood the science content, and they choose not to expand their knowledge of the matter further (Jee & Anggoro, 2012). Of course, this problem is more likely to occur in casual studying than in classroom settings because an exam, for example, would reveal that learning has not occurred. However, Jee and Anggoro (2012) focus on science comics specifically as a tool for informal learning rather than using them in tandem with or in place of traditional textbooks in classrooms.

Tribull (2017), on the other hand, argues that it is advisable to employ science comics and textbooks side-by-side at lessons: comic books can appear less intimidating than textbooks, and they produce better learning results in introductory science courses than textbooks. It would make sense, then, that some or all textbooks be replaced by comic books or graphic novels. However, the matter is not that straightforward: if the language of a comic book is too didactic, the reader may feel disconnected from the text and story (Tatalovic, 2009). Moreover, comics may be a poor learning tool for people with low background knowledge of science because those people usually benefit from full, detailed explanations (Jee & Anggoro, 2012). Also, if comics are an unfamiliar medium to the reader, they may have to spend cognitive resources on the comprehension of the narrative at the cost of learning (Jee & Anggoro, 2012). However, Tribull (2017) argues that ”the use of the narrative can engage students and increase student desire to learn more complicated material, especially if they do not self-identify as interested in science” (p. 458). Moreover, “[t]he narrative structure of comics could make scientific material easier to comprehend” because narratives follow a similar pattern as our everyday experiences (Jee & Anggoro, 2012, p. 200), for instance when a character goes to a new place and learns how things work there. Including some

kind of narration in a science comic is advised in science comics guides (e.g. Tribull, 2017; McDermott, Partridge & Bromberg, 2018). A plot should not be overly complicated, however; it should be able to communicate the key ideas and concepts, and comic creators should focus on how to communicate their ideas through images (Tribull, 2017). Also, science comics should be rather straightforward and easy to understand – one comic should hold one simple message (McDermott, Partridge & Bromberg, 2018). This is especially the case with short strip comics.

Naturally, narratives need characters whose adventures to narrate to the reader. Many science comics feature scientist characters, and they are portrayed as a diverse cast of many races and genders in order to make the comic appeal to different kinds of readers and to break the stereotype of a white male scientist (Jee & Anggoro, 2012). Characters, especially personificated inanimate objects, can improve engagement (McDermott, Partridge & Bromberg, 2018). In science comics, "[n]onhuman entities are often represented as human-like characters" (Jee & Anggoro, 2012, p. 201), i.e. the nonhuman entity is portrayed as a personified, active character with a face and a name. Personification of characters may make it easier for readers to relate to them, consequently wanting to spend more time reading about them (Jee & Anggoro, 2012). Relating to characters may also create stronger memories (Jee & Anggoro, 2012). Also, having previous experiences about how humans act could help young readers infer the mechanistic, causal reasons behind the actions of nonhuman entities (Jee & Anggoro, 2012).

As both Tatalovic (2009) and Jee and Anggoro (2012) mention, science comics should aim to both educate and entertain, and this can be achieved through close cooperation of scientists and comic creators. When scientific accuracy becomes the most important aspect of a science comic, its entertainment value may be forgotten (Tatalovic, 2009). Humour is only one way to entertain the reader but used well, it will make a science comic less intimidating (McDermott, Partridge & Bromberg, 2018). It is especially important for a science comic to be entertaining when it is meant and used for informal learning. In formal education, a teacher may be able to motivate students, but when reading a science comic in their leisure time, readers can control freely how much time and attention they invest in a particular comic (Jee & Anggoro, 2012). This means that if a science comic is not interesting or it does not motivate to read and learn, the reader will most likely abandon it. Comics have the ability to "make informal learning more engaging, enjoyable, and memorable" (Jee & Anggoro, 2012, p. 204), and I see them as a perfect medium for communicating science in a way that focuses not only on the cold, hard facts but the experience also.

The audience of a science comic should be kept in mind when planning and making the comic. Tribull (2017) mentions that the target audience dictates a comic's vocabulary and context,

and that a narrative is quite necessary in order to communicate ideas to a young audience effectively. McDermott, Partridge and Bromberg (2018) also advice comics creators to use simple language in their science comics; that is, the kind of language that a layperson will understand. Jee and Anggoro (2012) mention that both the storyline, characters, and humour have to be age-appropriate. Naturally, readers' backgrounds, knowledge of a topic and cognitive abilities dictate what they can and want to read – to put it bluntly, an average 6-year-old child will not probably benefit from a text aimed at professional physicians, and a physician may find a text targeted at 6-year-olds boring. Using audience-appropriate contexts and analogies of some kind can be argued to be a requirement of an effective comic since, as McDermott, Partridge and Bromberg (2018) mention, a science comic should make an abstract concept tangible by describing concepts with memorable metaphors and using analogies to connect the concepts to reader's everyday lives. The contexts and previous knowledge of an audience will be discussed later in the section 2.3 Science communication.

Research about science comics usually focuses on printed comic books, but the Internet and social media especially are particularly suitable platforms for science comics as well. Thanks to social media, it is easy for science communication to breach the barriers of the stages of science communication. In social media, science comics that were originally intended for scientific communities may go viral and reach a new audience, such as the general public (McDermott, Partridge & Bromberg, 2018). Indeed, Tribull (2017) lists many popular science comics series that are available to read online. As we will find out in the next section, the active engagement of scientists in the communication process is seen as important in the modern conception of science communication. In the Internet, this is easily achieved: it is effortless to share content, find an audience, give feedback, and for the content creator and their audience to exchange ideas. Also, much of online content is free to read, and especially short comic strips are fast to read, making them ideal for the hectic modern life. Since social media is a large part of the modern human's life, I find it to be an optimal platform for informal learning and science comics.

Science comic scholars have pondered the matter of artwork. Tatalovic (2009) argues that if the artwork is too polished, it may steal attention from the science content of the comic or misrepresent the science; however, if there is little to no plot in a science comic and the comic's aim is to convey information, stunning artwork may help to hide it. Images in comics arguably do increase interest, but still, ultimately, they should be able to convey complex and abstract ideas (Tribull, 2017). After all, “[c]omics are not about art. They are about conveying a message in a graphic form.” (McDermott, Partridge & Bromberg, 2018, p. 2). Therefore, when it comes to

science comics, the aesthetic beauty seems not to be the measure of how "good" the art is – rather, the better an image communicates an idea, the better it is. In this sense, science comics appear to be closer to functional design than fine arts.

Even though several visual means, such as illustrations, graphs, and plots, are already regularly used to present data, comics can provide information in ways that other media cannot. As McDermott, Partridge, and Bromberg (2018, p. 2) argue, "[g]raphs and plots are for accurately conveying data, diagrams are for accurately depicting a system or setup, and comics are there to help people understand an idea." This fact has been acknowledged in the research of multimedia as well: different modes should be used where they serve their purpose best, for instance, writing for telling and images for showing (Kress, 2003). In other words, comics should not be used to replace other media that have shown their functionality, but in the same way that graphs and plots have their respective, established uses, comics should be used for the purposes that they serve well. Comics have been argued to be better instruction tools than videos because a reader can see each step clearly and instantly and compare the before- and after-pictures (Tatalovic, 2009). Many teachers use animations as an educational tool, but comics hold some advantages over them: students can read comics and study at their own pace, and they rarely revisit an animation that is usually shown only once during a course (Tribull, 2017). Reliable studies comparing comics to other visual media have not been produced; some studies indicate that animations produce better learning outcomes than static images while other studies indicate that the opposite is true (Jee & Anggoro, 2012). Similarly, a comic brochure seemed to be more effective at conveying some information than a photo brochure and vice versa (Rodriguez & Lin, 2016). In addition, the learning outcomes of comic books have not been compared to animations or static images (Jee & Anggoro, 2012).

That is not to say that comics are useless in teaching and learning: the combination or pictures and written text appears to be a functional learning tool. Even though it has not been explicitly shown that those who study from science comics score better results than other students, it is worthwhile to consider other advantages of educational and science comics over other tools. After all, standardized test results should not be the sole focus or goal of learning as is emphasized by the ecological understanding of learning (discussed in section 2.3). Comics are able to both show and tell, that is, both show visually and explain verbally what is happening (McCloud, 1994). Reading illustrations in comics alongside written text can ease the struggle of learning scientific jargon and increase engagement with the material (Tribull, 2017). This is supported by McCloud (1994): pictures are received information, and they are interpreted instantly and we do not need formal education to make sense of them. Writing, on the other hand, is perceived information: in order to

decode the abstract symbols that comprise the written language, we need education (McCloud, 1994). Also, embedding words into pictures may promote learning because of spatial contiguity; understanding which elements of an image the written text refers to becomes easier when the elements and the text are in close proximity (Jee & Anggoro, 2012). Comics embed words into images in three ways: 1) narration; 2) speech and thoughts of characters; and 3) sound effects (Jee & Anggoro, 2012). Therefore, it is possible to combine written text and images in multiple ways, which results in versatile and rich descriptions of processes, reactions, and phenomena that help the reader imagine the sounds surrounding a situation – for instance, a chemist's narration of their working process could be written in speech bubbles and sound effects could be used to show the sounds of chemical reactions. Even though written text and illustrations are often used side by side in text books also, Tatalovic (2009) argues that comics are a different medium from science book illustrations even if the illustrations are cartoony or even if the book's text describes the images or is otherwise closely connected to the images. This is an understandable distinction – as has been established, one advantage that comic books have over single illustrations or cartoons is the sequential juxtaposition of images that offers many possibilities for showing and telling of events. All things considered, I assume that comics, especially science comics can be a noteworthy option for autonomous learning even if a reader is capable and willing to read scientific publications. If the reader is not familiar with scientific concepts and terminology, a science comic intended for informal, autonomous learning may potentially help familiarize the reader with the underlying science facts and theories more effectively than a scientific article.

### 2.1.2 Previous studies on comics and learning

Previous case studies and experimental studies support the assumption that comics make more enjoyable learning materials than other media, especially linear text and traditional textbooks (e.g. Rodriguez & Lin, 2016; Lin & Lin, 2016; Obare, Birungi, Deacon & Burnet, 2013; Krishnan & Othman, 2016; Topkaya, 2016). In their experimental study, Rodriguez and Lin (2016) found that their comic brochure group perceived the material interesting to read, informative, and cognitively engaging more often than their photo brochure group. In Lin and Lin (2016), the comic book made achievers of all levels more interested in learning about nanotechnology than the text booklet, and all kinds of achievers would choose a comic book for informal learning rather than linear text. Some participants said that comics are more interesting and easier to understand because images help them imagine things whereas linear texts contain too many words (Lin & Lin 2016). In their feedback, the participants in Obare, Birungi, Deacon, and Burnet (2013) praised the comic books as

both educational and enjoyable, one student commenting “[t]his book is cool, inspiring and very educative.” (p. 211). Krishnan and Othman (2016) hope that pupils notice that science is not a difficult subject to learn and that their motivation will improve when their academic achievements increase and remembering scientific facts becomes easier thanks to science comics. Topkaya (2016) noticed that students were enthralled by the imagery in the instructional comics and that the visual elements made them pay more attention to class activities.

Researchers have found that participants' knowledge increased when using comics as an educational material. Hosler and Boomer (2011) found that after their biology courses, content knowledge had increased in both the treatment and control groups, indicating that comic books are not worse educational tools than traditional textbooks. This is a noteworthy discovery: there is no pedagogical reason not to use comics in education. Also, Obare, Birungi, Deacon and Burnet (2013) found that after reading the comic books about HIV and AIDS, students were more knowledgeable about the diseases than those who did not read the comic books. In Rodriguez and Lin (2016), the comics group performed better in terms of knowledge than the control group, but the difference was not statistically significant. The authors question the effectiveness of comics: even though comics are often considered to be a suitable tool for conveying complex ideas, the comic brochure was not significantly better at improving readers' knowledge. However, opposite results have been discovered also: Topkaya (2016) found that, thanks to comics' ability to explain complex ideas clearly, students learned more from instructional comics than from other learning materials. Krishnan and Othman (2016) found that the pupils in their experimental group achieved better academic success and were more likely able to recall scientific facts than the pupils in the control group. These aspects allegedly led to the improvement of their higher order thinking skills.

Lin and Lin (2016) found that while both the text booklet and the comic book increased readers' knowledge, there was no significant difference between the two media. Their comic book was a more beneficial learning tool than the text booklet for medium achievers while low achievers benefited from them equally. High achievers, however, benefited more from the text booklet, probably because they “have better comprehension of and are familiar with reading brief science texts” (p. 1381). Lin and Lin (2016) mention that whereas science texts use “[s]cientific descriptions and relationship statements of cause and effect” to communicate facts, science comics break the descriptions and statements into dialogues (p. 1381). The direct descriptions may be more helpful to high achievers while medium achievers may find the dialogues and stories more helpful (Lin & Lin, 2016). Medium and low achievers, however, may confuse their understanding of the narrative with understanding of the scientific content, and some misconceptions were identified

later on during interviews (Lin & Lin, 2016). Similarly, Hosler and Boomer's (2011) study suggests that the comic book approach is especially suitable for non-major and weaker major biology students.

When changes in attitude were investigated, comics were found to be beneficial for improving attitudes. Hosler and Boomer (2011) found that those students whose content knowledge was lower than average in the pre-instruction test showed significant increase in their attitude scores in the post-instruction test, indicating that comic books made them more engaged and interested in biology. Conversely, if a student had completed several biology courses prior to the research period and scored high on the biology attitude scale at the preinstruction test, their attitude on biology did not significantly improve on the postinstruction test; this suggests that attitudes may reach a saturation level (Hosler and Boomer, 2011). Furthermore, an increase in the comic attitude scale correlated with an increase in the biology attitude scale and vice versa, and the correlation is "stronger and more positive" for students whose content knowledge was below average to begin with (Hosler and Boomer, 2011, p. 315). Also, in an experimental study by Rodriquez and Lin (2016), a comic brochure was found to be more effective at improving readers' attitudes than a photo brochure; however, the difference was not statistically significant. Compared to the photo group, the comic group was more willing to vote for candidates who were pro–wind energy and to pay more for wind energy, for example, and the results indicate that the comic brochure was able to create positive changes in behaviour more effectively (Rodriquez & Lin, 2016). Topkaya (2016) found that the attitudes towards environmental problems improved significantly more in the treatment group than in the control group, suggesting that instructional comics were a useful medium in improving attitudes. Both Rodriquez and Lin (2016) and Topkaya (2016) link the change in attitude to the entertaining and humorous ways their comics presented scientific ideas.

In Obare, Birungi, Deacon and Burnet's (2013) study, practical factors can be seen to have affected and confused the data. Even though the authors found that those students who read the educational comic books were more likely to discuss about the diseases, their attitudes toward HIV-infected children improved, and they were likelier to get tested for or counselled about HIV, the overall likelihoods were lower at endline than at baseline (Obare, Birungi, Deacon and Burnet, 2013). The result indicates that in general, the project activities were not successful. Possible reasons for this are that the activities had to be organized during weekends and in the evening after school, which made attending difficult for some students; self-administered questionnaires that did not allow clarification of difficult questions or unfamiliar terms; and the fact that participants answered the questionnaires anonymously and the participants were not the same in the pre- and

post-tests, making it impossible to examine individual development of knowledge and attitudes. This was a unique result among the studies used in this review; in all other studies, the average scores were always higher at post-test than at pre-test even if individual participants' scores decreased. Furthermore, in all other studies employing both pre- and post-intervention tests, all participants answered both tests. If generalizations are made from Obare, Birungi, Deacon and Burnet's (2013) study, the situations where research participants do not answer both the pre- and post-intervention questionnaires are to be avoided. Moreover, including several educational activities in addition to studying comic books may influence the research project and end results, possibly preventing the study to meet its goals.

In some ways, comics were found to be inferior to other media. In Rodriguez and Lin's (2016) experimental study based on participants' perceptions, a brochure containing text and photos was found to be more credible than a comic brochure; the authors note that this may be due to comics' reputation as children's entertainment. However, the difference is not statistically significant (Rodriquez and Lin, 2016). Some participants in Lin and Lin's (2016) study said that science content can be found more easily and directly from linear text while in a narrative the content is indirect and interweaved into the story. Lin and Lin (2016) also note that it is possible to make linear science texts more readable to low achievers, who often struggle with comprehending scientific literature, by presenting information using understandable words, paying special attention to the clear flow of text, and keeping in mind what is the audience's earlier knowledge of the topic in question.

We are now familiar with the history and scope of science comics: previous research indicates that there are several noteworthy reasons to use comics as teaching materials and that comics are a valid tool that produce learning results. As science comics are by nature a medium to communicate research and findings of science, it is necessary to examine some integral theories of science communication.

### 2.2 Science communication

The term science communication can be divided into scholarly communication – from experts to other experts – and public communication of science – from experts to the public – but in the anglosaxon culture, science communication is commonly used to refer to science popularization (Karvonen, Kortelainen & Saarti, 2014). In this paper, I will use **science communication** to refer to public communication of science. The word public refers to a group of actively discussing people

while an audience is a passive group of spectators and listeners (Karvonen, Kortelainen & Saarti, 2014). Both terms have been used of the consumers of popularized science. In addition, in the English language, the word *science* has come to mean natural sciences (Karvonen, Kortelainen & Saarti, 2014), and that is possibly the reason why science comics that originate in the anglosaxon culture most often deal with topics within physics, mathematics, medicine, biology, and so on.

The traditional approach to science communication is to assume that the audience suffers from knowledge deficiency – this approach is often called the deficit model or the "diffusionist" conception (Bucchi, 2004). The word "deficit" implies that the audience simply lacks factual knowledge and the only thing separating them and specialists is an information gap (Bucchi, 2004). This deficiency is filled by feeding citizens scientific knowledge (Bucchi, 2004). According to the model, information flows up to down, from scientists to the public, and the audience, thirsty in their ignorance, will simply absorb all information given to them (Bucchi, 2004; Karvonen, Kortelainen & Saarti, 2014). It must also be noted that according to the diffusionist conception, science communication is not the duty of scientists but of media and specialized science communicators such as journalists and science museums; this way, scientists are able to detach themselves from the communication process and criticize the scope and style of media coverage of different topics (Bucchi, 2004).

The continuum model of science communication (illustrated in figure 1) was developed as a response to the strict model of science communication where there are only two levels – scholarly communication and public communication – and a one-way flow of information (Karvonen, Kortelainen & Saarti, 2014). The continuum model contains four levels: intraspecialist, interspecialist, pedagogical, and popular (Bucchi, 2004). On the intraspecialist level, experts within a certain scientific specialization communicate their research to each other, typically via papers published in the speciality's journal; on the interspecialist level, the types of communication and texts are more varied – they can be e.g. interdisciplinary articles or papers shared among researchers who work within different specialities of the same discipline; on the pedagogical level, the theories that the scientific community has already discussed and agreed on are included in textbooks; on the popular level, science and research is communicated to non-scientists via media (Bucchi, 2004; Karvonen, Kortelainen & Saarti, 2014). As was discussed earlier, science comics can be found on all these levels, and in the form of e.g. comic books and comic strips, they have been included in scientific journals, in textbooks and classrooms, and in informal learning.

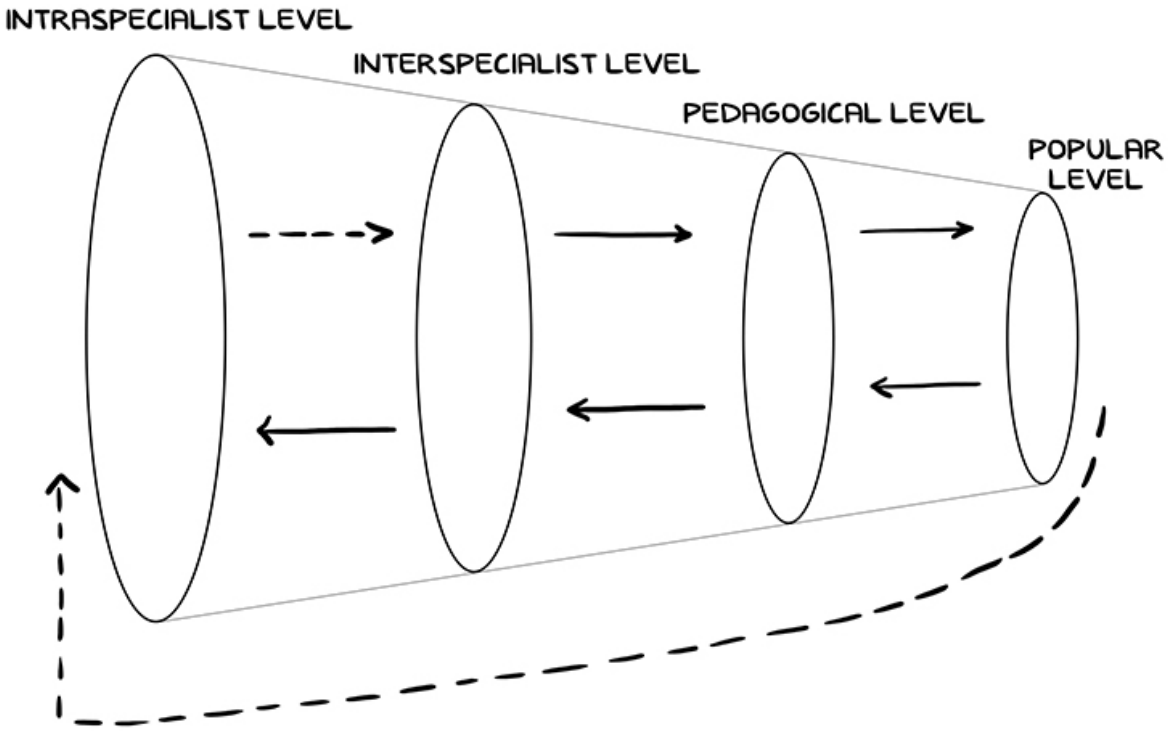


**Figure 1. Illustration of the continuum model.**

According to the continuum model, science communication is ”a continuity of texts with differences in degree and not in kind across levels.” (Bucchi, 2004, p. 115). This means that the texts on the non-specialist levels (pedagogical and popular) are less detailed, and tentative theories and facts are presented as certain on these levels (Bucchi, 2004). The model is the shape of a tapering funnel to illustrate this discarding of scientific details and the simplification of theories from level to level (see figure 2 for a visualization) (Bucchi, 2004). However, communication does not always flow in a direct trajectory from the specialist levels to the popular: enthusiastic discussion of a scientific matter on the popular level may ignite research and discussion on the specialist levels (Bucchi, 2004). Sometimes scientists use the popular level as a medium “to reach a large number of colleagues rapidly” and only veil their message to seem like it is intended for the public (Bucchi, 2004, p. 119). Other times, the public arena is a site of scientific production, such as community-based research, and not merely the receiver of information (Bucchi, 2004). The engagement of all parties is another thing that separates the continuum model from the deficit model: scientists are seen as active discussants in the communication process instead of passive onlookers who simply produce information for others to distribute and absorb. As was discussed

earlier, this is visible in science comics also: many scientists wish to participate actively in the communication process and draw their own comics (McDermott, Partridge & Bromberg, 2018).

### 2.3 Autonomous learning

Familiarizing ourselves with theories of learning will help us gain a more profound understanding of both the process of science communication and the power of science comics. The approaches relevant to this study are the constructivist approach to learning, ecology of learning, and the situated learning model. Constructivist approaches of learning have made classroom teachers aware that their students ”will build upon an existing knowledge framework and accept or reject new ideas in the context of what is already known” (Stocklmayer, 2001, p. 8). Similarly, a science communicator has to keep their audience's backgrounds and previous experiences in mind. The audience will compare new information to their existing knowledge and real-life experiences, and if they fail to find a connection between them, they will reject the information. In the light of this, it is extremely important that the science communicator finds a connection between the scientific

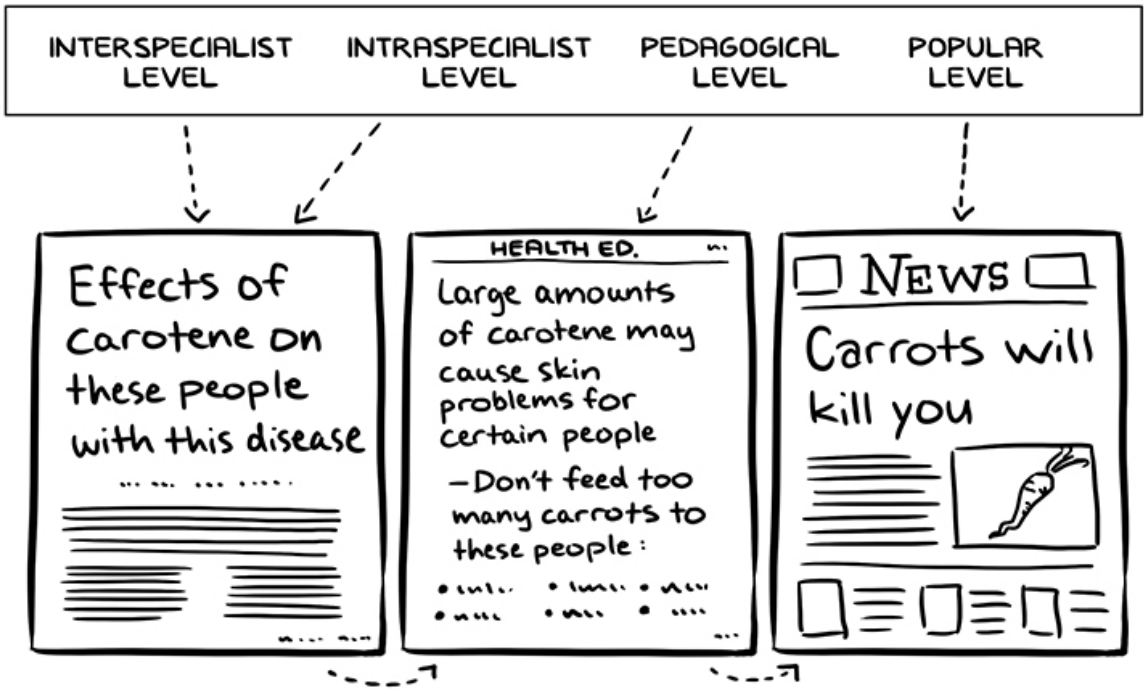


**Figure 2: Discarding of facts according to the continuum model.**

information and everyday life (Stocklmayer, 2001). This means that in order to understand a phenomenon and the scientific explanation of its causes and consequences, people need a context that they use to link the explanation to their everyday lives. An example of this is chemical reactions and how they affect laundry washing (see figure 3). As was discussed earlier, science comics use "show and tell" and perceptual experiences to provide these contexts.

Science comics are intended for autonomous learning so ecology of learning offers a useful point of view to them. Van Lier (2004) describes ecology of learning in the following way:

> The results of education that fall within the purview of standards, evaluations, performance reviews, accountability, and standardized tests are nothing but the shells that we find on the beach. They tell us that there is life in the ocean, but they do no more than give a hint of its nature and its variety. Ecology wants to find a way to look deeper and further; it will address the notion of the *quality* of educational experience, as different from the documentation of educational *standards* (p. 12; cursive original).

Autonomous learning rarely, if ever, involves any kind of evaluation or testing. Readers of science comics are self-motivated; they do not read science comics to pass an exam or to prove their knowledge to an authority, they read because they genuinely want to learn about the subject. Therefore, science comics have to adopt a different approach from school textbooks: they have to strive to communicate their message and truly make their readers understand the subject, and they have to make this in ways that keep the reader motivated and interested. In other words, the quality of a science comic lies not in the grades its readers would receive in a potential test but in its ability to educate, motivate, and entertain.

Science comics can also be examined in the context of the situated learning model. The model focuses on social, practical learning and involves the concept of Just Plain Folks (JPFs) who are not students or experts but "people who engage in problem solving in everyday life" (McLellan, 1996, p. 6). Moveover, "[b]oth the JPFs and the experts are engaged in activities that are situated in the cultures in which they work, within which they negotiate meanings and construct understanding" (McLellan, 1996, p. 7). In other words, JPFs have physical, social, and temporal working environments, and those environments guide their understanding and interpretation of new information. For instance, if a child often cooks with their parents, they will learn the practices and stages of work involved in cooking. Science comics can provide these "working environments" by taking their readers on figurative field trips, that is, to alien worlds and unfamiliar circumstances to learn about something new. Also, science comics can verbally guide readers in the interpretation of the comic and demonstrate visually, directly or indirectly, how JPFs can apply their new scientific knowledge and understanding to their specific cultures, such as by proposing actions to battle

climate change as *The Cartoon Introduction to Climate Change* does. In these ways, science comics can be used to bridge the gap between abstractions and JPFs' lives and cultures. However, if they are not able to interpret new information in meaningful and sensible ways, the information has failed to connect to their cultures and they cannot be expected to continue learning. For instance, many middle schoolers are not interested in learning about politics because they do not see how it affects their lives or how they can participate in decision-making. This is another reason why science comics should be targeted to a specific audience and why they must offer references to real-life contexts.

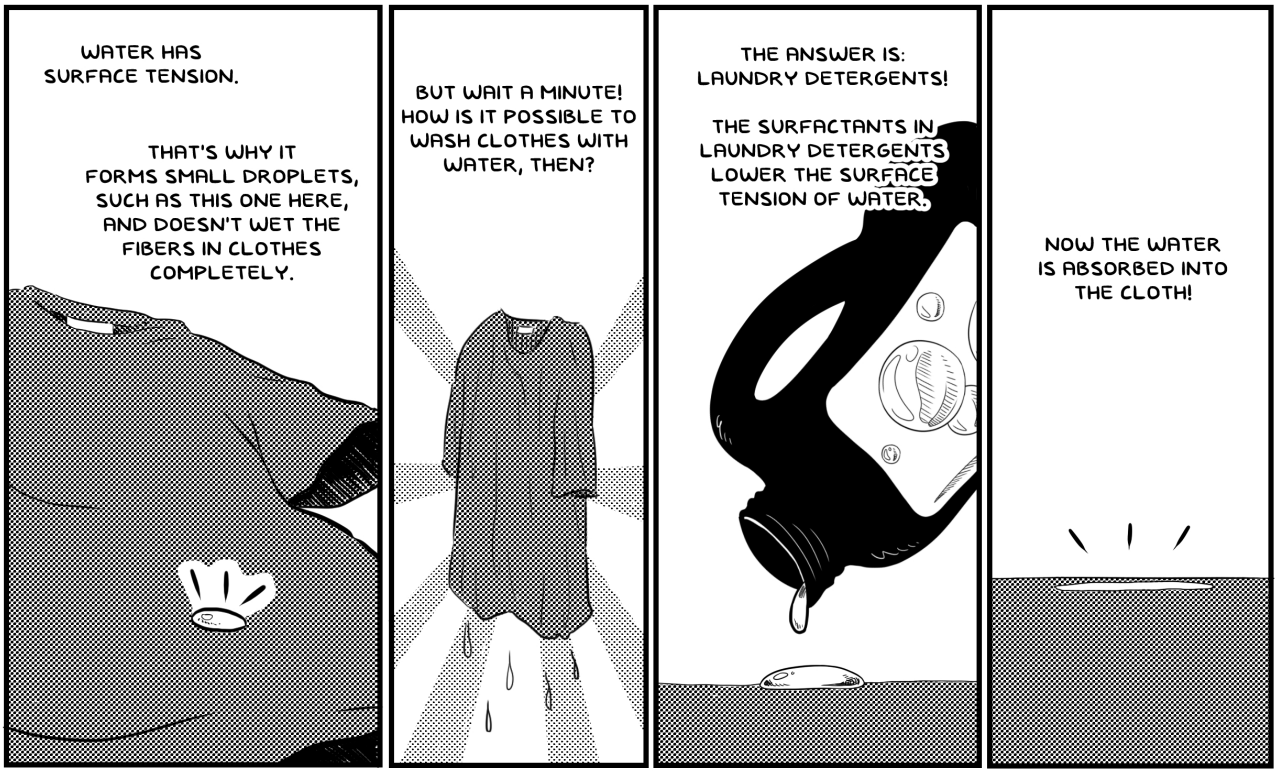


**Figure 3: An example of connecting new information to a person's existing knowledge.**

One especially interesting feature of situated learning is that “stories are very important for situated learning and for the social construction of knowledge” (McLellan, 1996, p. 7). Narratives both transfer information and “help people keep track of their discoveries, providing a meaningful structure for remembering what has been learned”, and act as “a vehicle for remembering” (McLellan, 1996, p. 7). Since JPFs often have to learn various skills and about several topics throughout their lives, it is extremely useful for them if information is provided in a way that makes memorizing and recalling it fast and easy. Moreover, stories are often shared within cultures, and consequently, narrations transfer information to community members and define the social

collection of knowledge. In these ways, situated learning acknowledges the ancient tradition of storytelling and transferring information through narration. Science comics follow this tradition, although often reaching a larger audience than a specific community or culture. As was noted earlier, not all science comics include narration, but many do, and in various studies narration was perceived to contribute to enjoyment and memorization (e.g. Jee & Anggoro, 2012; Tribull, 2017).

Reflection is also important in situated learning. Experts rely on experiential cognition, that is, their experience and expert knowledge; this results in faster thinking within their field of expertise, but the thinking may lack depth (McLellan, 1996). Reflective cognition, however, means deep thinking and reflection on information, and JPFs often have to resort to reflective cognition in order to process new information (McLellan, 1996). If I ask my grandfather, a chemist and an expert in paper-making, about the differences in paper qualities, he is able to give me an instant answer, whereas I, not having any experience in paper-making, would have to first learn the different papermaking processes, connect the information to what I already know about chemistry, and truly reflect on the why and how of the topic before giving the answer. I argue that science comics and narration aid in reflection because narration and characters help readers process new information and connect scientific phenomena to everyday experiences and activities. Also, they can recognize their own beliefs, habits, and actions in the narration, for instance, their attitudes towards climate change and environmental politics and spending habits, and reflect on them and find the reasons and validation for them.

### 2.4 On comics and entertainment

As one of the main goals of this study is to find the ways in which *The Cartoon Introduction to Climate Change* is designed to entertain its readers, we first have to learn what entertainment is. According to Merriam-Webster, the definition of *entertainment* is "amusement or diversion provided especially by performers", or "something diverting or engaging: such as (1): a public performance (2): a usually light comic or adventure novel" ("Entertainment," 2018a). (It is unclear to me whether it is "a light comic" or "a light comic novel" that is usually a source of entertainment. However, I assume that both interpretations are applicable here.) Oxford Dictionaries defines it as "[t]he action of providing or being provided with amusement or enjoyment" ("Entertainment," 2018b). Whether comics are performed by anyone is a matter of debate for another time, but what is certain is that comics are indeed a diversion; they distract the reader from their everyday life and take them to new worlds. Hopefully, they are also so engaging that they manage to grip and hold the reader's attention for long periods of time. They are sometimes amusing as well, and many people

claim that they enjoy reading comics. The word “comic” implies that comics are humorous by nature – however, as comic readers know and as has been mentioned in numerous studies (e.g. Zanettin, 2010), comics can and do deal with heavy and non-humorous topics also, and their goal is not always to make the reader amused or to laugh. Topics range from depictions of the horrors of holocaust (*Maus* by Art Spiegelman) to chilling horror stories (e.g. Junji Ito's work) to autobiographical comics about living with a mental illness. So what is it that makes comics entertaining?

Editorial cartoons use satire, irony and parody to be funny, while gag cartoons often rely on the combination between a drawing and its caption – together, they form a new, comical meaning that could not be achieved without the other (Zanettin, 2010). In some verbal jokes and cartoons, humour arises from structural incongruity which the reader resolves with information available elsewhere in the joke or cartoon; in others, the incongruity remains unresolved and may lead to new incongruities and absurdities (Zanettin, 2010). In comic panels and cartoons, “humour is often generated by the interplay of visual and verbal messages” – for example, wordplays get a new meaning when they are considered and interpreted together with an image (Zanettin, 2010, p. 38). However, this is not the only way to amuse readers because the theories exclude e.g. slapstick humour. In longer works, such as comic books and graphic novels, humour is “more generally a property of the text”, for example through the drawing style which may resemble a cartoony caricature-style, or language, for example by using “a peculiar speaking style” for characters (Zanettin, 2010, p. 44).

In his classic book *On the Comic and Laughter,* Vladimir Propp examines various ways of humour in theatre plays and prose literature. When it comes to characteristics, comic characters are those who are self-absorbed: either their positive or negative traits are exaggerated or they trust themselves too much (Propp, 2009). Therefore, revealing ugliness in a character or hidden flaws in their actions (as long as they are not shocking or do not cause pity) causes ridiculing laughter (Propp, 2009). The human body is a source of comic: ”involuntary physical functions are almost always funny”, as are disturbing body odours or ladies' perfumes, and ”[t]he human *face* can be comical in a great variety of ways”, especially the nose (Propp, 2009, pp. 32–33, cursive original).

Repetition, especially the repetition of physical characteristics, is often considered humorous: humans are expected to be individuals, each with their own unique inner lives, but when two individuals appear outwardly exactly alike, we suddenly assume that their inner beings are alike as well, and this sudden revelation and deviation from the expectation causes amusement (Propp, 2009). Another type of repetition is an appearance of characters who are alike in nature; these

characters are usually a pair, such as a parent and a child (Propp, 2009). Moreover, repeating a mental act too many times makes it lose its creative significance and become funny; an example of this is a teacher and lessons that remain unchanged year after year, causing amusement in students who learn about this (Propp, 2009).

In contrast, differences may be amusing, too: having a feature that distinguishes a person from their environment or from the norms of a group they belong to can cause laughter (Propp, 2009). For instance, a person with an atypical body part, such as a very long neck, or an exceptionally clumsy dancer may become laughed at. ”Making a human similar to an animal or comparing” them to one with perceived negative qualities, such as a pig or a donkey, or comparing them to a lifeless object or thing is perceived amusing; similarly, animals that show human-like characteristics, for instance a dancing dog, evoke laughter (Propp, 2009, p. 46). A character's profession may become the target of ridiculing, and also the activities and the professional's external form that are related to it (Propp, 2009), such as the diva-like manners of an actor.

Exaggeration may reach comical proportions: caricatures draw attention to a certain detail in a character – in their nature or physical form – by emphasizing it; parodies, on the other hand, exaggerate ”particular features” of an existing work of art, politics, or a person's life (Propp, 2009, p. 60). Everyday life is an inspiration for comic: ”[a] failure in everyday routine events caused by some equally minor circumstance will be comical” (Propp, 2009, p. 70), such as being startled by a harmless kitten and consequently dropping a heavy hammer on one's toe. Characters are also able to ridicule each other, especially when one of two characters deliberately creates a conflict between the characters by making the other one a laughing stock; this is called duping (Propp, 2009). Linguistic means of comic should not be forgotten, either: writers can employ puns and witticism, paradoxes, irony, and professional jargon to make the audience laugh (Propp, 2009).

Humour and jokes are, however, only one way to entertain an audience. Humans seek enjoyment and gratification from entertaining media, and individuals base their decisions of media-usage largely on where they are most likely to get enjoyment (Sherry, 2004). Different types of gratification have been identified in various studies, including emotional stimulation, entertainment, enlightenment, escape from everyday life, relaxation, and arousal (Sherry, 2004). It appears that when we are talking about entertainment, we are actually referring to gratification and reasons to use a certain medium or product, entertainment being only one type of gratification (Sherry, 2004). However, for the purposes of this study, I will use the term *entertainment* to refer to gratification and the different reasons to use entertaining media. For survey respondents, entertainment often equals enjoyment which “is seen as relief from overstimulation (through relaxation) or

understimulation (through arousal)" (Sherry, 2004, p. 330). Due to a large variety of options in entertainment, it is usually possible for a modern person to choose a medium that best suits their need, one that either arouses and stimulates their brain or provides a relaxing pastime experience. In addition, enlightenment is listed as one type of gratification, and that is what science comics will, hopefully, offer. In this light, it seems that the both sides of the common goal of science comics – to both educate and entertain – are intrinsically connected because both provide gratification. Different types of gratification can be seen in figure 4, and the types will be referred to in the analysis.

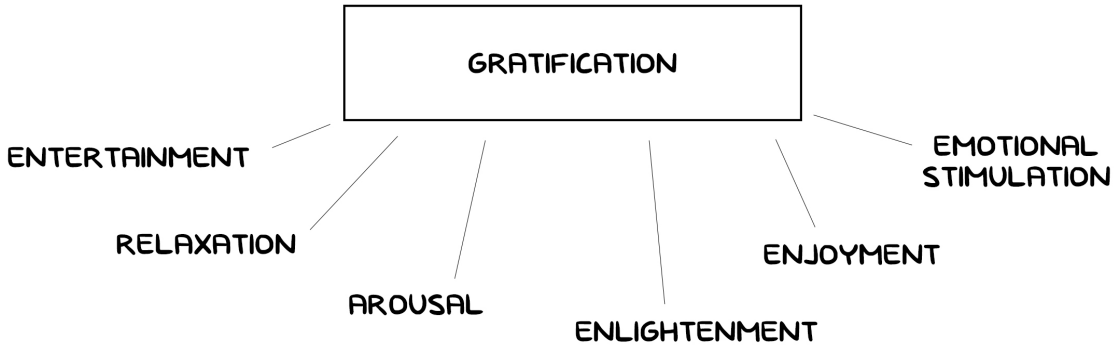


**Figure 4: Types of gratification (from Sherry [2004]).**

Sherry (2004) makes a connection between entertainment and flow. Flow is a state of intense focus and enjoyment that one may experience when they are engaged in a pleasurable task; flow is often associated with creative activities, but it can be achieved during any activity that is difficult enough to challenge an individual practitioner's skills but not so difficult as to frustrate them (Sherry, 2004). When consuming entertaining media, "[f]low state may be prevented by a mismatch between individual media use skill and the difficulty of the message. Therefore, an individual who lacks skills to read or interpret certain types of media will not enjoy the media experience" (p. 336). In other words, for a teenager, for example, a children's book may be too easy to read while James Joyce may be too difficult, and both reading experiences result in frustration and boredom. This is another reason why targeting a product at a specific audience and keeping the audience's abilities in mind is important. Also, if a cultural product is poorly executed or otherwise disregards usual conventions, it may result in a difficulty to read and understand the product, further leading to a disrupted flow and enjoyment (Sherry, 2004). In science comics, enjoyment may be prevented,

firstly, if the science content is too difficult for the reader to comprehend; secondly, if a reader is not familiar with comic book conventions and is not able to read and interpret the comics; and thirdly, if a comic is so poorly or freshly executed that reading it becomes too challenging. Flow and enjoyment contribute to readers' motivation to continue reading.

Similarities between the types of gratification and other definitions of entertainment can be identified, for instance, escape and Merriam-Webster's emphasis on diversion: entertaining media provide a diversion or escape from one's everyday life to alternative, fictional worlds where one can experience a variety of emotions (Sherry, 2004). Also, both Sherry (2004) and Merriam-Webster (“Entertainment,” 2018a) agree that in order to be entertaining, a work has to be engaging which can be interpreted as another expression for the state of flow. Regulation of emotions is present in the definitions of both Merriam-Webster and Oxford Dictionaries: both note on amusement as one feature of entertainment, Oxford Dictionaries mentions enjoyment, and Merriam-Webster mentions a light comic (or a light comic novel) and an adventure novel as sources of entertainment (“Entertainment,” 2018a; “Entertainment,” 2018b). A light comic may relax the reader and prevent overstimulation, and because adventure novels are usually thrilling and exciting to read, they can be thought of as an arousing experience that prevent understimulation.

## 3. Methods and materials

In this section, I will explain the methods used in this study – content analysis and multimodal analysis – as well as the basis for the interview. Also, I will describe the data and materials used in the study and the reasons for choosing them. The reasons for the triangulation of methods and data will also become apparent here. First, I will describe the materials and data; second, I will describe the general principles of the methods; and third, the specific ways in which they are applied to this study.

### 3.1 Materials

The data in content analysis is not a result of an accident but "products of chosen procedures and are always geared toward particular ends" (p. 81) – therefore, researchers must always explain how they gathered their data, and what are the history, purpose, and other background information of their texts (Krippendorff, 2004). In this study, the main material is *The Cartoon Introduction to Climate Change* by Grady Klein and Yoran Bauman and published by a nonprofit organization Island Press. Bauman has a doctoral degree in economics and is a self-titled "the world's first and only stand-up economist", so he has experience in turning scientific and scholarly theory into entertainment, and Klein is an artist and designer who has likewise worked on several science comic projects (Klein & Bauman, 2014). Before *The Cartoon Introduction to Climate Change*, the authors have co-created two volumes of *The Cartoon Introduction to Economics*, and Klein has collaborated on the comic book *The Cartoon Introduction to Statistics* (Klein & Bauman, 2014). *The Cartoon Introduction to Climate Change* has also been translated into French and Chinese, and a PowerPoint presentation, intended specifically for high school and college teachers, of climate change that features illustrations from the book is available online (Stand-Up Economist, 2014).

Climate change affects the climate and environment in several ways. For instance, climate change increases extreme weather events, such as heavy rainfalls and heatwaves, around the globe (”Climate Change,” 2014). Sea levels rise because of the heat expansion of sea water, melting mountain glaciers, and decrease of the Greenland and Antarctic ice sheets (”Climate Change,” 2014). Because climate change is a global problem and affects each and every human being on the planet, we should be knowledgeable about its causes, progression, prevention, and outcomes. *The Cartoon Introduction to Climate Change* responds to this need by popularizing the science of climate change and by offering both scientific facts and calls to action in a format that may be more easily digestible than traditional textbooks even for young readers. I chose this comic book for my

analysis because it was available as a digital copy through my university library, so I was able to view and browse the book and ensure that it was suitable for my research before purchase. I chose only one book for the analysis because I wished to focus on one specific work where the ways to entertain and the ways of presenting science content remain as consistent as possible. Moreover, by reading and analysing a whole comic book, I believed I would gain a sound understanding of the narrative techniques that a comic book might employ.

The secondary material of this study is an interview with Olivia Walch. The remainder of this section is dedicated for accounting and analysing the interview data, and the starting points for the interview are explained more thoroughly in section 3.2. Walch works as a researcher and has a doctoral degree in mathematics. She creates science comics for The Nib, an online magazine focusing on journalistic comics, and she has also included them in her doctoral thesis and on her webcomic site and blog. Walch started making science comics in high school, and she still makes them whenever she wants to learn something new; after all making comics "forces [her] to learn", and the process is comparable to doing homework (personal communication, September 24, 2018). She says that "making a comic is a really good exercise in distilling something down to its essentials, and by the end I always feel like I have a much deeper understanding" (personal communication, September 24, 2018). Her comment resembles many other scientists' description of the result of creating a comic: the process improves their thinking (Humphrey, 2014). This strengthens the notion that while educational comics are useful tools for learners and readers, scientists can also use them for reflective thinking. As was mentioned earlier, reflective cognition is central in situated learning (McLellan, 1996); however, in this case, experts are the ones engaging in reflective cognition and deep thinking of a topic. I assume that the theories of constructivist approaches to learning work in the other direction here also: when making a comic, researchers gain a deeper understanding of their subject because they are forced to reflect on what they know, find the essential points from the theory, and link scientific theories to familiar real-life contexts. Also, many comics creators find the process of making a comic immensely entertaining, and creators often experience the flow during it. Therefore, it might be that the criterium of a successful science comic – that it should be both educational and entertaining – applies also to the creative process. By adapting their knowledge into a comic and a narration, researchers also engage in transferring information, create structures that help readers remember the information, and record their discoveries, all of which is essential in situated learning.

When Walch starts making a science comic, she first chooses a storytelling angle, such as "The actual math of neural nets is SURPRISINGLY simple" or "Blockchain can seem weird and

contrived as data structure until you try to break it", and the angle guides her work during the creation process of a comic (personal communication, September 24, 2018). I see that a tight focus is important for science comics, especially short comics such as the ones Walch makes, because it prevents the narration from meandering and potentially confusing the reader. McDermott, Partridge and Bromberg's (2018) notion of dedicating one comic to one simple message both concurs with Walch's statement and supports my argument. Walch says that making comics is similar to teaching calculus in the sense that she uses analogies to help her audience understand abstract concepts: for instance, going downhill represents the ease of multiplying numbers, climbing uphill resembles the hardness of factoring the numbers, and training a neural net is comparable to tuning a piano (personal communication, September 24, 2018). In other words, Walch links abstract concepts to contexts that are familiar to her readers, and in this way, she realizes the theories of science communication and learning in her practical creative work. She popularizes science by explaining theories in an understandable manner, omitting all excess information, and focusing on the most important facts, which is exactly how the continuum model guides to do (Bucchi, 2004).

Concurring with the constructivist approach to learning, Walch says, "[a]udience is everything"; content has to match its audience, otherwise the creator risks further confusing the reader (personal communication, September 24, 2018). For instance, Walch says that her science comic *An Introduction to Neural Net* is intended for people who are knowledgeable in mathematics while *The Blockchain Is Secure* is targeted at the general populace; however, she says that many readers still found *The Blockchain Is Secure* confusing, so the the match between content and audience was not satisfactory (personal communication, September 24, 2018). As was mentioned earlier, the target audience dictates the vocabulary and context of a comic (Tribull, 2017), and because Walch's science comics are targeted at Just Plain Folks, those contexts have to make sense in JPFs' cultures so that they are able to properly interpret and comprehend the messages of her comics (McLellan, 1996).

Walch maintains reader interest by including special elements, such as GIF animations, in her comics "to add some pizazz" (personal communication, September 24, 2018). Animations add one more mode – movement – to a comic. As Kress (2003) says, different modes are best equipped for different purposes, so with animations, it is possible to present certain events and information in a way that is not possible in, say, writing or still image. Moreover, Walch says, "[y]ou're asking somebody to pay attention and learn something, and if information is dense, it can be draining for them to read your comic" (personal communication, September 24, 2018). As has been mentioned earlier, it is important that science comics intended for informal learning motivate and engage the

reader (Jee & Angorro, 2012), and Walch seems to agree with this. I believe that elements that punctuate verbal text with pauses may decrease the reader's cognitive load. The elements also present information in alternative, intriguing ways and may increase the entertainment value of the comic by providing different kind of stimulation, amusement, and/or diversion, and may make the learning experience memorable. Walch herself comments that comics make learning science content memorable, and that “if the point is to communicate information, being more memorable is almost always going to help in that mission” (personal communication, October 1, 2018), concurring with Jee and Anggoro (2012) who also say that science comics make informal learning engaging and memorable. Moreover, because informal learners are able to control the time they invest in learning, GIF animations and other elements may be both a reward for reading and an incentive to continue reading, as a kind of gratification which Sherry (2004) sees as a crucial part of entertainment. After all, autonomous learners are self-motivated, and a comic that motivates and inspires them to read further removes obstacles from the learning experience and makes it enjoyable.

Walch's jokes tend to be verbal but she also likes ”adding goofy expressions on the characters” (personal communication, October 1, 2018) – as Propp (2009) says, the human face has the capability of evoking amusement, as do characteristics that seem out of place. Walch's jokes are usually scripted, although sometimes she adds them spontaneously, and she prefers subtle jokes that “don't interfere with the educational narrative, but do add a little flavor” (personal communication, October 1, 2018). Deducing on this comment, her main goal seems to be education and informing, and entertainment is a vehicle that makes the educational experience more enojyable for the readers of her comics. She separates scientific instructions and humour by dedicating the narration for explaining and adds humour in the panels in handwritten type that is embedded in the images (personal communication, October 1, 2018). I see this separation as an efficient way to inform the reader about which parts of the comic should be taken seriously – a matter which may not always be clear. Once the reader learns which parts are serious explanation and which are humorous remarks, they can be certain that all information in narration is intended to be factual. Also, since Walch writes the jokes by hand, there is also a visual distinction between facts and jokes, not only spatial. Walch also says that some jokes, such as funny comments in speech bubbles, are not ”necessary for the explanation, but it makes the experience of reading it lighter and less of a slog” (personal communication, October 1, 2018). Effortless reading contributes to the flow a reader may experience when reading (Sherry, 2004) and thus to the entertainment value of a science comic. Also, as Jee and Anggoro (2012) point out, showing characters' speech and thoughts visually is a feature of comics that may enhance learning.

### 3.2 Methods

The methods used in this study are content analysis and multimodal analysis. In principle, content analysis is "a systematic reading of a body of texts, images, and symbolic matter" (Krippendorff, 2004, p. 3). "Text" is not limited to written material – it can be images, art of any kind, maps, symbols, etc. (Krippendorff, 2004). For an analysis to be considered "systematic", it has to follow "rules that are explicitly stated and applied equally to all units of analysis" (Krippendorff, 2004, p. 19). Therefore, I will explain my analytical process later in this section. Research techniques within content analysis must be reliable and produce results that are replicable, valid, and open to scrutiny, and because direct observational evidence of a phenomenon is not available, empirical validation or some other kind of backing besides the researcher's opinion is required (Krippendorff, 2004). In order to validate my findings and analysis for the research questions, I will use literature from the fields of science comics, science communication, autonomous learning, entertainment, and multimodality. A researcher's background always guides their interpretation of content and the researcher must be aware of their limitations (Krippendorff, 2004). I am white, abled, highly educated, Finnish, middle class, and belong to the ethnic majority. Also, I am a comic artist and have received education in graphic design. Moreover, I am not reading the materials casually but with analysis in mind, and that approach will affect my understanding of the text. These aspects, as well as my personal history, will guide my interpretation of data and also my commentary of findings.

Texts do not hold meanings per se – it is the individual readers who give texts meanings (Krippendorff, 2004). Therefore, it is not possible to find a single true meaning in a text, and interpretations made of the same text by different individuals need not be the same or similar (Krippendorff, 2004). However, cultures affect individual readings of texts, and how designated populations use certain texts must be acknowledged (Krippendorff, 2004); for instance, if a Finnish anthropologist studies an artwork originating in an ancient Aztec culture, they have to consider the original usage of and meanings assigned to the work instead of interpreting it from their own individual perspective. For this reason, criteria for validating results must be stated explicitly (Krippendorff, 2004), and the anthropologist might validate their analysis by referring to what is known of the Aztec culture. However, even though readers assign texts meanings, creators of texts are not powerless: Kress and van Leeuwen (2006) mention that communication occurs within a society, and different communicators, be they e.g. artists or speakers, express social meanings in their respective products. Moreover, Kress (2003) says, "'[s]cientificness' is a social construct, a meaning that arises in and signals belonging to a community and its practices" (p. 173). Therefore,

*The Cartoon Introduction to Climate Change* should not be interpreted as a product detached from its societies which are the scientific and the (science) comics societies. The production of the book has quite likely followed the practices and conventions of both of those societies, at least to some extent, so similarities and differences should be accounted for in the analysis.

Content always has a goal, be it to communicate information, "invoke feelings, or cause behavioural changes" (Krippendorff, 2004, p. 24), and the goals affect analysis. The goal of *The Cartoon Introduction to Climate Change* is to convey information and educate its readers on the topic of climate change, and the comic should be analysed with this goal in mind. Moreover, "the conceptual environment of a text, the situation in which it plays a role", that is, the context in which a text is used and/or examined guides interpretation, so researchers must state the contexts in which they are working (Krippendorff, 2004, p. 33). The context of my study is an academic master's thesis research that focuses on the data's communicational, entertainment, and educational properties, and I will consider the usage of *The Cartoon Introduction to Climate Change* in its intended context as a science comic and learning tool. This kind of clarification of the context is required in content analysis because it determines which inferences a content analyst can draw from a text (Krippendorff, 2004). These inferences are used to answer research questions; content analysts rely on inferences to answer their research questions because the phenomena they study are not directly observable (Krippendorff, 2004). In other words, since it is not possible to show a direct connection between the use of jokes in a science comic and enjoyment, an analyst can rely on the context of communication, entertainment, and education and how jokes and enjoyment work in that context in order to make the inference "readers enjoy science comics more if they contain jokes". Abductive inferences are drawn from signs that are inferred to be a result of a certain phenomenon; these inferences are "descriptive accounts of texts and what they mean, refer to, entail, provoke, or cause" (Krippendorff, 2004, p. 85). For instance, the signs that are used to create a joke in *The Cartoon Introduction to Climate Change* are a result of a tradition of jokes, and these signs and what they refer to will be described in the analysis.

The theory of multimodality complements content analysis because both disciplines are concerned with the meanings of whole texts and not only isolated parts of them. Also, both agree that texts do not mean anything per se, that is, isolated from the culture in which they were produced or interpreted; all meanings of texts are socially constructed. At the heart of multimodality is a mode which is a resource or material that has been culturally and socially shaped and can be organized for meaning-making (Jewitt, 2009). For instance, written language is a resource that consists of written symbols, and by organizing these symbols in a certain way we are able to

communicate a variety of meanings. Meanings of signs are culture-specific, and social norms affect the creation, reading, and interpretation of them, and even though modes communicate meanings themselves, the co-appearance of different modes affects meaning-making (Jewitt, 2009). When different modes co-appear, the text formed by them is called multimodal; a multimodal text is "any text whose meanings are realized through more than one semiotic code" (Kress and van Leeuwen, 2006, p. 117). A cereal box, for example, is a multimodal text because it realizes meanings through all its modes, such as the written text, images, colours, and texture of the box. Therefore, combinations of modes should be studied as whole texts in order to discover the meanings that readers might find in them. Because comics consist of multiple semiotic codes such as verbal text and images, they can be considered multimodal texts. The modes to analyze in *The Cartoon Introduction to Climate Change* are the written language (words, i.e. the contents of the textboxes and speech bubbles) and the images (the contents of panels; graphs, diagramms, characters, backgrounds, typography, and composition). I will consider the semiotic meanings, connotations, and denotations of individual signs when they are relevant to the analysis. For instance, when a sign can be interpreted in multiple ways, it changes the interpretation of the whole text – perhaps it creates a joke or helps a reader link an abstract theory to their everyday life.

Since I am a comic artist myself, this study has a strong autoethnographic orientation which is apparent in my analysis and comments. Moreover, in order to deepen the understanding of science comics and especially the creative process of making them, I have adopted an ethnographic orientation to the study and included an interview with a science comic artist. I conducted a structured interview with comic artist Olivia Walch via email. In a structured interview, the order and wording of questions is predetermined, and the questions are open-ended so that the interviewee is able to use their own words (Hirsjärvi, Remes & Sajavaara, 2005). The reason I chose to interview Walch via email is that she is able to think her answers more thoroughly while she is writing than while talking. Moreover, for me as a researcher, it is far more easier to keep record of and examine her answers when they are in written form. First I asked general questions regarding the creation process of her science comics, and after reading her answers, I asked her further questions focusing on humour in her comics. I have included the questions in appendix A. Obviously, Walch has not contributed to the making of *The Cartoon Introduction to Climate Change*, and therefore, no direct inferences can be drawn from her working method to those of Bauman and Klein. However, I think that learning about the creative process of one science comic artist will give an insight into how many other creators make their science comics. After all, science comics often have one specific goal – to educate and entertain – so I believe that comic creators

apply many similar working methods to their work in order to attain that goal.

Usually, content analysis contains the steps of unitizing, sampling, coding, and reducing data. Unitizing is the act of systematically creating units of segments of text, and the methods of unitizing must be stated and justified (Krippendorff, 2004). I will unitize the comic by separating the written and visual modes and the different elements of *The Cartoon Introduction to Climate Change* – textboxes, speech bubbles, drawings – into distinct units. This will help me examine the modes and elements separately before analysing the combinations of them. Sampling means that the analyst focuses on e.g. a certain theme in a book, and observations are limited to "a manageable subset of units" that are representative of the all possible units (Krippendorff, 2004, p. 82). In this study, I will not limit my analysis to samples but rather identify the ways to adapt science and entertain the reader in the whole book. Recording and coding are done for the purpose of preserving a text (Krippendorff, 2004), but *The Cartoon Introduction to Climate Change* is already preserved and widely available and requires no recording. Data can be reduced by combining occurrences into type/token statistics, for example (Krippendorff, 2004). I will be able to reduce the analyzable data by not discussing each and every example of a certain type of, for instance, visual joke, but rather focus on the features the jokes share.

The analysis complied with the following steps: first, I read the book and identified its ways to 1) present science; 2) adapt science content into a comic form; and 3) entertain the reader. Specifically, I examined the interplay of the textboxes, drawings, and speech bubbles and how the interplay affects the communication of the science content. Also, I considered in which ways the interplay provides gratification for the reader, for instance, by stimulating emotions or promoting enjoyment. Secondly, I analysed how each of the elements contribute to science communication and entertainment separately. Thirdly, I categorized similar findings under specific headlines in order to make the analysis coherent and in order to avoid redundant repetition. Finally, I identified similarities between the findings and Walch's answers.

## 4. Analysis: Science communication and entertainment in practice

The different aspects and features of *The Cartoon Introduction to Climate Change* can be analysed from the perspectives of both of the research questions, and some of my observations concerning entertainment overlap with my observations of the science content and vice versa. For this reason, I will answer both of the research questions while analysing each mode and element of the book whenever necessary in order to avoid redundancy and to keep the analysis coherent. I will begin with the analysis of the visual mode and move on to the analysis of the written mode. Similarly, whenever possible, I will begin by analysing the means of communicating science and then proceed to the analysis of entertainment. Henceforth, I will refer to *The Cartoon Introduction to Climate Change* as CICC.

Before we begin, we have to define the different elements of the comic that are under investigation in order to clarify the analysis. The elements are the textboxes, the speech bubbles, and the drawings. I consider the speech bubbles and drawings as the contents of panels while textboxes act as their own separate entity. I have marked these elements in figure 5 to clarify them visually. In addition to examining them separately, I will analyse interplay between these elements, i.e. the comic form.

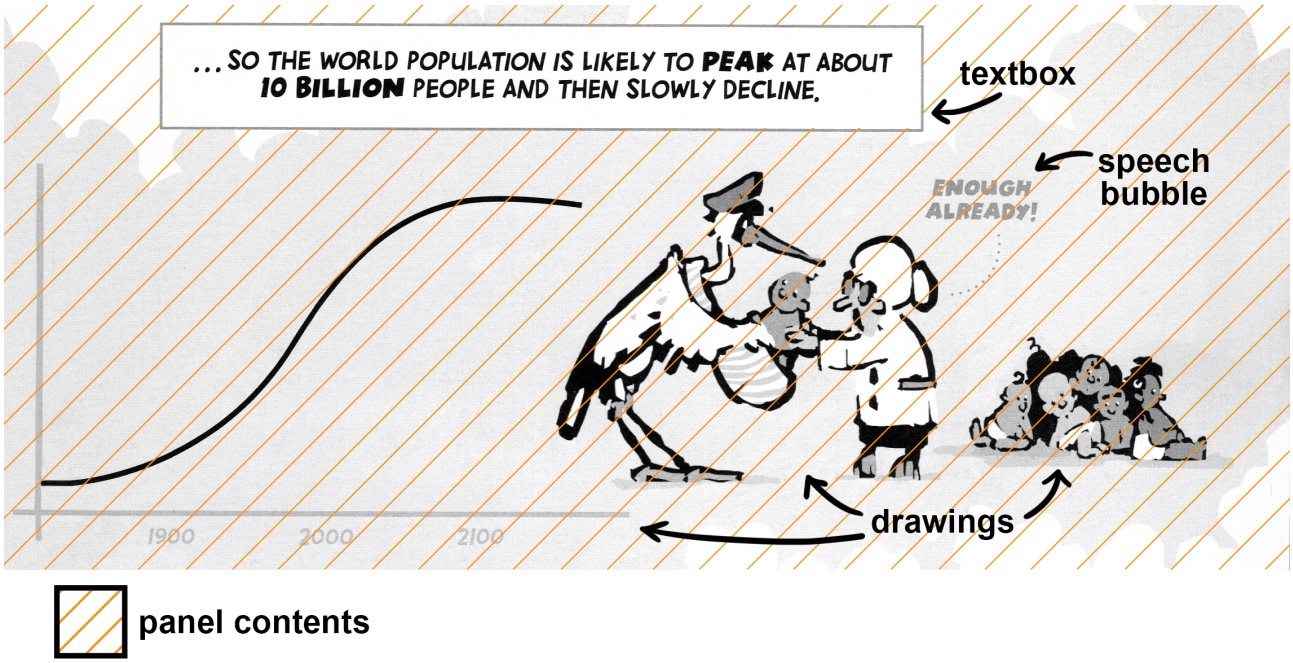


**Figure 5: The elements of the comic.**

### 4.1 The visual mode

The drawing style of the comic is simplified and cartoon-like. That is, the comic is drawn in carefree black strokes that vary in thickness and the only colours are shades of grey. Round shapes are not completely round and some lines are not perfectly straight. In places, the art style approximates abstract: areas have been coloured with uniform fills of different shades of grey, without gradients to imply depth or shape; sometimes backgrounds consist of allusive shapes such as four white squares on a grey background to imply a window. This kind of art style is very far from what we are used to seeing in science text books which are usually illustrated with detailed, full-colour, realistic depictions of plants, organs, and the planetary system as well as cross sections of objects, for example.

However, scientific illustrations do not necessarily have to look "natural"; after all, what they depict are not "real" but theoretical objects, generalized and diagrammatic presentations of real-world entities that are not tied by their real-world aspects, such as colours and boundaries (Kress, 2003). These illustrated entities are representatives of their everyday counterparts but in a drawing, a viewer is only able to see a fragment of the actual entity, a fragment that is frozen in time and place and follows the regulations of a theory that is applied to it (Kress, 2003). This notion gives a great freedom to illustrators and science comic creators: the visual accuracy of an object or entity may not be necessary in science communication. It is also a feature of science communication that follows the theory of the continuum model: some aspects and details of the actual event or entity are omitted for communicational purposes. Nevertheless, despite abstraction, illustrated objects in CICC are recognizable, and reading and understanding of the content is not hindered, therefore making reading enjoyable and gratifying. Moreover, in Kress's (2003) study on the modes of scientific expression, a teacher is shown to distinguish scientific expression from artistic expression and everyday realism: students are only allowed to use the black-and-white of a lead pencil for scientific illustrations. In accordance with this, the black-and-white illustrations of CICC seem to apply a very similar understanding of an appropriate mode of delivery for scientific content.

However, even though most drawings in the book follow the principle of visual simplification and abstraction proposed by Kress (2003) – for instance, the single-celled organisms are just generic lumps and not of any species in particular – and often the authors have given creatures completely made-up names (Klein & Bauman, 2014, pp. 104–105), there is one instance where the depicted creatures look very close to their real-life examples and are named with their actual names (Klein & Bauman, 2014, p. 99). These small sea creatures, coccolithophores, pteropods, and foraminifera, are in danger because of ocean acidification, and the way they are presented –

realistically, on a dark background, which sets them apart from the usual visual style of the book and the spread that is otherwise light – brings drama and gravity to the situation: it is not some general, abstract lumps that are in danger, it is these specific creatures. Such drama and sudden change from general to specific is not typical in science texts, and this dramatic change in method of treatment both visually and verbally is possible only in comics. It is also a way to stimulate the reader's emotions and increase the effectivity of the message.

Viewing angles and the positioning of objects in the panels also makes the comic appear scientific. In the panels of CICC, the most important things are placed on the foreground while the backgrounds are less detailed and get little attention, and they can be as simple as distant hills drawn in aerial perspective. The comic is drawn from an eye-level camera angle which makes the reader feel that they are observing events unfold from a neutral, scientific point of view: "front-on" presentation of images or illustration is typical in scientific communication because an eye-level view implies objectivity and a situation that resembles the setting of scientific examination, that is, where there is a viewer and a displayer (Kress, 2003). "The positioning is neither to the side – which would indicate lesser involvement – nor is the viewer below or above the element shown, something that would indicate difference in power." (Kress, 2003, p. 177) I imagine that in a science comic, the eye-level camera angle is very convenient when the reader is a mere observer and the drama and action do not require the positioning of the reader above or below characters.

Graphs and diagrams are an equally important part of scientific content in CICC. As was discussed earlier, other visual means besides comics can be used to accurately present data, so it makes sense to include them in a comic also. After all, other visual means are easy to incorporate in a visual medium, and they are often necessary to argue one's case. In CICC, graphs are incorporated

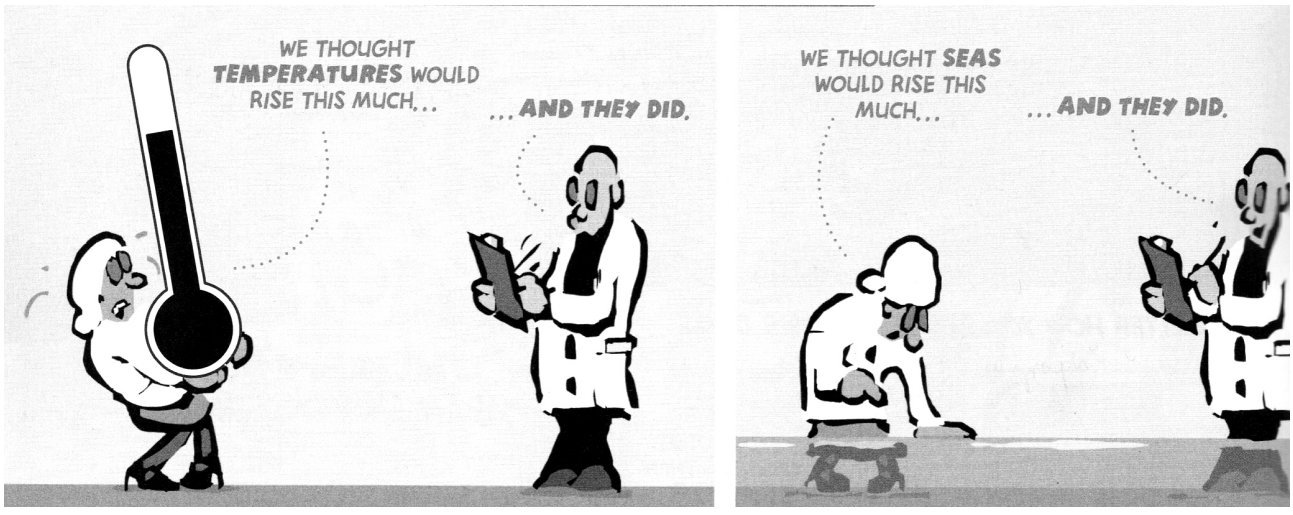


**Figure 6: An alternative way to illustrate a graph in CICC.**

in panels. The scientist characters are used to describe the graphs, and in this way, to help the reader interpret them. They also point at the important parts that the reader is supposed to focus on. Often, the scientists stand inside the graphs, and they may have been drawn dressed according to the theme of the graph, for instance, in beach clothes when explaining the appearance of warm periods in the history of the Earth's average surface temperatures (Klein & Bauman, 2014, p. 29). In some cases, the most important parts of a graph, such as the peak average surface temperatures, are highlighted visually – it makes the peaks look as if they are glowing (Klein & Bauman, 2014, e.g. p. 29; see also figure 14). In certain places, the graphs are not traditional graphs with lines and curves at all, but objects and elements of an image that are used as graphs. For instance, a risen water level represents how much the scientists (who are standing in the water) estimated the sea level would rise, and a smelly cloud emanating from a pile of cow faeces depicts how much the methane levels were estimated to rise and how much they have actually risen (Klein & Bauman, 2014, p. 124; see the illustration in figure 6).

The panels of the comic are full of interesting, funny details, both visual and verbal, but they do not appear to hinder the reading; rather, the reader can take their time perusing the panels as carefully as they wish, and then continue reading at their own pace. It may be argued that the drawings and the jokes in the book make the reading experience lighter because they offer small breaks and alteration from the fact-heavy narration in the textboxes. This observation is in line with Walch's comment about how including jokes here and there in a science comic makes the reading experience “less of a slog”. Moreover, it can be argued that the details make the comic memorable; for instance, laughing at the situation where a scientist refuses to take any more babies from a stork (Klein & Bauman, 2014, p. 5) might create a strong memory that over-population is a problem. Occasionally, the jokes and funny details distract the reader but since, as Tribull (2017) says, the reader can always determine their own reading pace and since they can always return to the point where they lost concentration, this does not appear to be a great problem. Concurring with Walch's comment, the numerous, amusing details decrease the density of the science content, so the jokes in CICC may also be a way to maintain reader interest and motivate the reader to continue reading the book: if reading the science content begins to feel too heavy, the reader can rest their mind for a moment by examining the details. Depending on the reader, I assume that perusing the details can be gratifying; the gratification results from amusement, enjoyment, and emotional stimulation. Alternatively, the reader is free to ignore the disracting details and focus on the actual narration and science content.

Pertaining to the physical dimensions of various elements in CICC, visual size is sometimes used to draw attention to something. Because different characters and other elements of drawings are placed side by side in comics and a reader gets used to seeing them in certain sizes, it is easy to notice when something grows out of its proportions or shrinks smaller than it was previously. For example, on page 182 (Klein & Bauman, 2014), a $CO_2$-character has grown unusually large and now fills the whole page, demanding the reader's attention; see appendix B for the illustration. In addition to the noticeable change in size, its dominant position on the page is acknowledged verbally: the narration says, “In sum, while **offsets** and other efforts to tackle non-fossil-fuel emissions might help **a bit**... … we have to make sure they **don't distract us from our main**

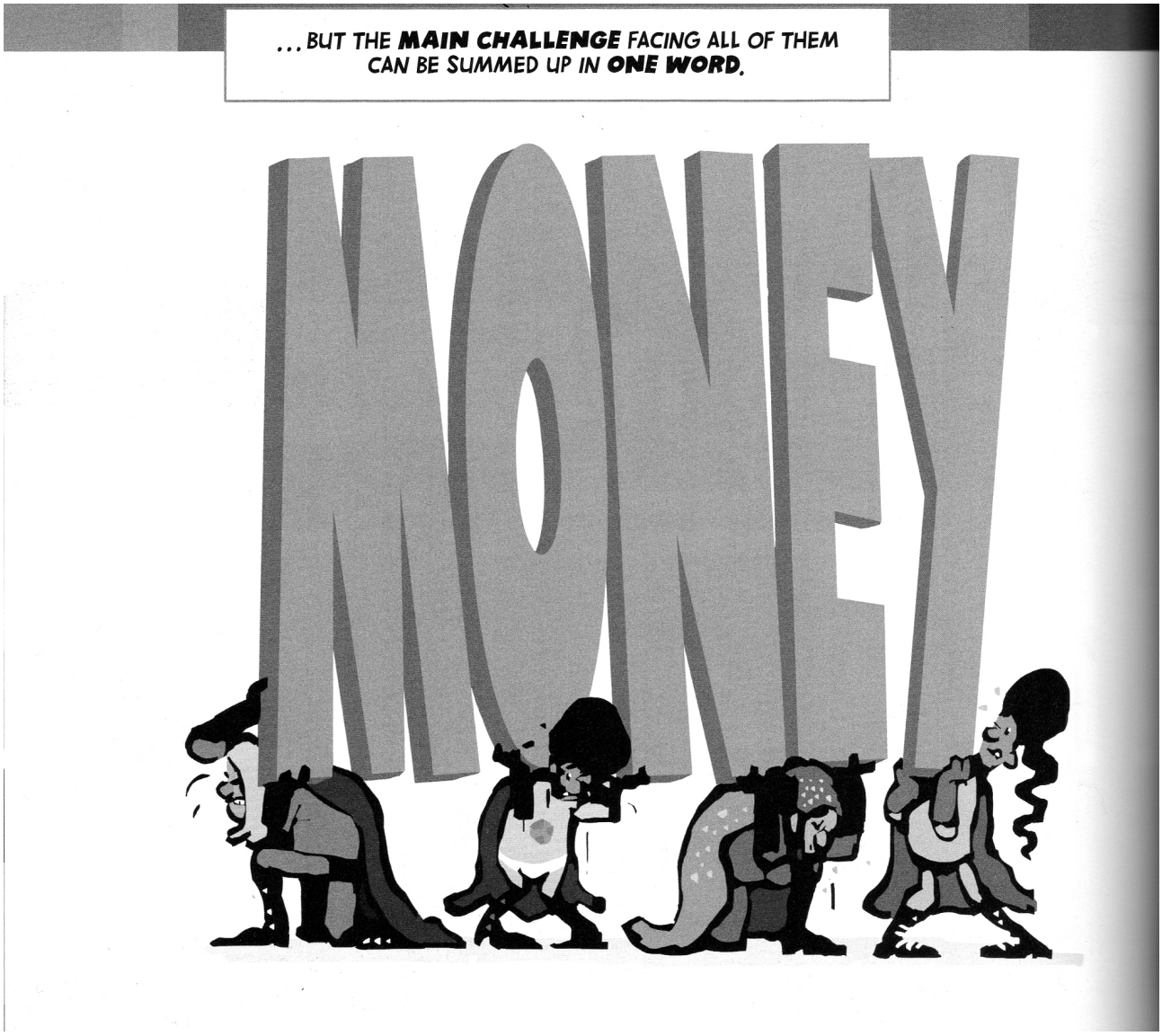


**Figure 7: A size difference of text.**

**task**.", and a speech bubble continues, "We need to **reduce $CO_2$** from **fossil fuels**" (p. 182, bolding original). Earlier, the book has explained different methods to encourage industries to reduce their $CO_2$ emissions, and by way of these visual and verbal descriptions, it draws the focus back from the methods to the "real problem". The manipulation of visual size can also be used to increase the importance of a certain element: for instance, on page 152 (Klein & Bauman, 2014) and in figure 7, the word *money* has been drawn to fill a quarter of the page, and the reader can deduce the matter of finances to be a pressing problem because it weighs down the superheroes of clean energy. In these ways, size differences are used for communicational purposes, but also for eliciting an emotional response in the reader: great size often implies threat or another formidable force.

As the narration in CICC recounts the history of the planet Earth, some specific points in time are visualized in the form of timelines; see figure 8 for an example. The scale of the timelines is from 4,6 billion years ago to the present day, and the timelines are directly attached to textboxes that each narrate changes in the evolution of life or the living conditions on Earth. The timelines are grey and the specific periods of time that are examined in the comic are marked as black bars of varying length. There is ever only one black bar per a timeline and only one timeline per panel. The periods of time are examined separately and in a sequential order. The black bars extend either from the very beginning to some point in the middle of the timeline, or they mark a period of time in the middle of the timeline, or they start from the middle and end at the present day. This is yet another way to make comprehending science content as effortless as possible – time is, after all, an abstract concept and trying to put something as long as 4,6 billion years into perspective surely is beyond human capacity. Also, probably for this very reason, the reader is spared from extraneous


**Figure 8: An example of the timeline in CICC.**

information, which is preferable in science communication according to the continuum model: even though the narration of history already focuses on the things that are most relevant to the topic, the specific time periods are kept rather vague. However, when numbers become important, they are written out and given attention by bolding them, for instance in, "Between about **2.8** and **2.3 billion years ago**, however, the green things did something perhaps even **more important**" (Klein & Bauman, 2014, p. 19, bolding original).

By way of comical visual depictions, the comic handles with humour the things that the reader may find scary or disgusting; it renders death mundane by presenting it in a ridiculing light, for example. A dead cow can be seen laying on its back with its legs comically pointing towards the sky, almost like it fell off its standing feet. Meanwhile, a goat is looking at the corpse placidly and a farmer is at the everyday chore of mucking out next to the corpse (Klein & Bauman, 2014, p. 18). On page 15 (Klein & Bauman, 2014), the victim of a murder is laying on his back with a kitchen knife stabbed into his big stomach, his mouth has been transfixed open comically, some of his fingers are still pointing rigidly, and his nose is very big. Moreover, judging from the victim's fancy clothing, the situation mimics a traditional detective story where the murder victim is either rich or noble or both. According to Propp (2009), facial features and expressions are a source of comic as are atypical body parts – in this case, the huge belly of the victim. The comic and unrealism of the situation aspire to make the reader feel amusement rather than abhorrence. In more formal science texts than the comic, death is usually treated objectively as a natural event in the cycle of life, but a humorous method of treatment fits better in a science comic where many other things are not handled objectively or seriously either.

The next section will deal with the verbal mode of the comic. It will cover various ways to communicate science as well as ways of verbal humour.

### 4.2 The verbal mode

Both *The Cartoon Introduction to Climate Change* and Olivia Walch's science comics follow the same division regarding written informational content and entertainment; in the textboxes, the narration consists strictly of information only, while verbal jokes can be found only in speech bubbles. As I argued in the analysis of the interview with Walch, this helps the reader to distinguish facts and entertainment from each other. The speech bubbles, on the other hand, contain scientific and factual content in addition to jokes, but my experience and assumption are that for most readers, it is easy to distinguish the facts and the jokes from each other and that the presence of jokes does

not undermine the credibility of the facts or hinder the reading and learning of them. Previous research on science comics does not mention the separation of factual information and verbal jokes and, therefore, does not comment on the advantages and disadvantages of it. However, Lin and Lin (2016) do mention that science texts can be made more accessible to low achievers by ensuring that the text flows clearly, and I suggest that dedicating textboxes to factual narration contributes to the clarity of the text. Moreover, I think that the division might be helpful for so-called high achievers also since they are able to read only the absolutely factual parts of the comic – after all, in Lin and Lin's (2016) study, some high achievers comment that they prefer finding the factual information in a text directly, and science comics often contain other text besides the actual science content.

In CICC, omitting unnecessary information often seems to apply to numbers and figures. This is in accordance with the continuum model of science communication as well as the situated learning model. It is not always necessary for a lay-person to know the exact figures as long as they understand and remember, say, what a graph looks like and what it represents. Therefore, in CICC, numbers and figures are provided only when they are relevant and make sense to the reader. When certain figures are so important that the creators wish the reader to keep them in mind, they are mentioned in the book multiple times; moreover, in those cases, it is usually more sensible to write the figures in numbers instead of drawing the same graph or visual analogy over and over again. This is the case with the difference in the carbondioxide levels in the atmosphere since the start of the industrial revolution compared to present day – 280 ppm versus 400 ppm. It should be noted, however, that 280 and 400 as numbers are relatively small and therefore the difference in them is easy for the human mind to grasp. Moreover, the visual mode may be used to replace explanatory written text when omitting extraneous details, e.g. numbers. For instance, if the goal of an illustration is to draw attention to a temperature difference, it is not necessary to attach a numerical scale beside the illustration, especially if the temperatures are disclosed in adjacent speech bubbles (Klein & Bauman, 2014, p. 60).

The language is colloquial, easy to understand, and it is without professional jargon. Excessive use of scientific terms is avoided which is the preferred situation in science comics and when communicating science to the public (McDermott, Partridge & Bromberg, 2018; Bucchi, 2004). However, some proficiency is expected of the reader because they have to know the basics of science subjects – after all, the book does not explain what a cell is or where abbreviations such as $CO_2$ come from, for example. Thus, the language and content are not overly simplified. The book does not talk down its reader, and it provides the necessary scientific terms that the reader needs in order to be properly knowledgeable in the subjects and to be able to participate in discussions

concerning the topics. In other words, the book does not only increase the reader's understanding of the topics, it also increases their vocabulary. As Tribull (2017) says, vocabulary must be designed according to the needs and abilities of the target audience, and I think that the aforementioned matters reflect the book's intended audience which, deducing from the teachers' materials relating to CICC, are high school and college students. I assume that using complex language in CICC is possible due to the fact that the comic is indeed book-length. After all, even though McDermott, Partridge, and Bromberg (2018) advice comics creators to use simple language, their guide is mainly targeter at creators of short comic strips. CICC has ample space to explain difficult words and ideas. In my opinion, the language is not too didactic, thus dodging Tatalovic's (2009) concerns that the reader would feel disconnected from the text. Here is an excerpt of the narration:

> For a **simplified version** of the Milankovitch story...
>
> … Imagine we're in **Canada** during a **glacial period**.
>
> The Milankovitch cycles eventually create conditions with **strong seasons**.
>
> **Hot hot** summers. **Cold cold** winters.
>
> That causes **ice and snow** to slowly give way to **land and water**.
>
> (Klein & Bauman, 2014, p. 34 (bolding original))

From this short excerpt, we can see a few ways in which the vocabulary and syntax of the comic differ from didactic and scientific texts. For instance, writers of scientific texts are advised against using colloquial phrases such as “give way to” or repeating an adjective in order to emphasize it, and would use an adverb for that purpose instead. Also, all clauses should contain a verb, which is not always realized in CICC. The text also seems to be narrating its events rather than explaining them in a strictly didactic manner: “Imagine we’re in Canada…” Often, the language and style is conversational due to the use of dialogue. I claim that this type of familiar, colloquial language helps the reader feel more connected to and engaged with the text than if the language were completely didactic, hence increasing their enjoyment of the text.

Since texts are products of certain societies and follow the conventions of the said societies, considering the differences and similarities to other texts produced by and in the societies is an integral part of the analysis of texts (Krippendorff, 2004; Kress, 2003). One such convention is the more or less fixed scientific format for delivering scientific information and it is this format that guides the way in which CICC is constructed, how it communicates scientific facts, and how it entertains the reader. The book has many similarities to science textbooks and other scientific texts. Much like many other science books, the comic book offers some experiments that the reader can try at home, such as measuring one's average home temperature in order to understand how

scientists measure the Earth's average temperature (Klein & Bauman, 2014, p. 52). Some footnotes and sidenotes are included within the panels: a suggestion to go to the glossary or a previous page of the book often appears in a speech bubble (Klein & Bauman, 2014, e.g. p. 34), but a side note can be found in, for instance, a banner that is attached to a plane (p. 18). Other footnotes and all references, however, have been written at the bottom of a page or in the vicinity of a graph (Klein & Bauman, 2014, e.g. p. 82). Like many other science texts, the comic book has been divided and organized into parts and chapters including an Introduction-part, and it contains a glossary at the end of the book.

In some ways, however, the comic book is different from other science texts. Its comic-form and humour are the most apparent aspects that separate it from a typical science text. Scientific texts and science text books, especially ones intended for formal learning, convey an air of objectivity and neutrality. In a similar vein, the tone in the textboxes in CICC is neutral and declaratory: they merely recount events and provide scientifically proven information. However, the creators have found a way to include opinionated statements in the comic by making characters voice them. For instance, when a textbox narrates “Many of the changing circumstances in the world today are caused by humans...”, a dragonfly next to the box comments, “Boy is that an understatement!” (Klein & Bauman, 2014, p. 103). Also, characters make statements that imply their biases through their body language. As the dragonfly utters its comment, the Rich World -character sprays it with something, possibly bug spray, thus creating a metaphor of how the humanity, especially the “rich world”, is destroying the environment (Klein & Bauman, 2014, p. 103). In another instance, when visiting a museum of the history of the humankind, a father is completely focused on his phone, ignoring the artefacts around him (Klein & Bauman, 2014, p. 107). The panel is preceded by a textbox that says that adapting to the changing environment will be easier for the wealthy, and the father is an example of a wealthy person who has the privilege of not having to care about his surroundings. In the next panel, he turns his back to a statue depicting a poor family, sitting on the statue's edge and still fiddling with his phone. These can be interpreted as the creators' comments on the political situation where the well-being and success of the rich world is esteemed higher than the well-being and success of the people in other countries, and how the rich world ignores the consequences of their actions to the rest of the world. Including these kinds of politically charged statements is possible in a book that is intended for autonomous learning and that does not claim to be an authoritative source of information. I assume that these moral and ethical comments invoke emotions and stimulate the reader, increasing the entertainment value of the book.

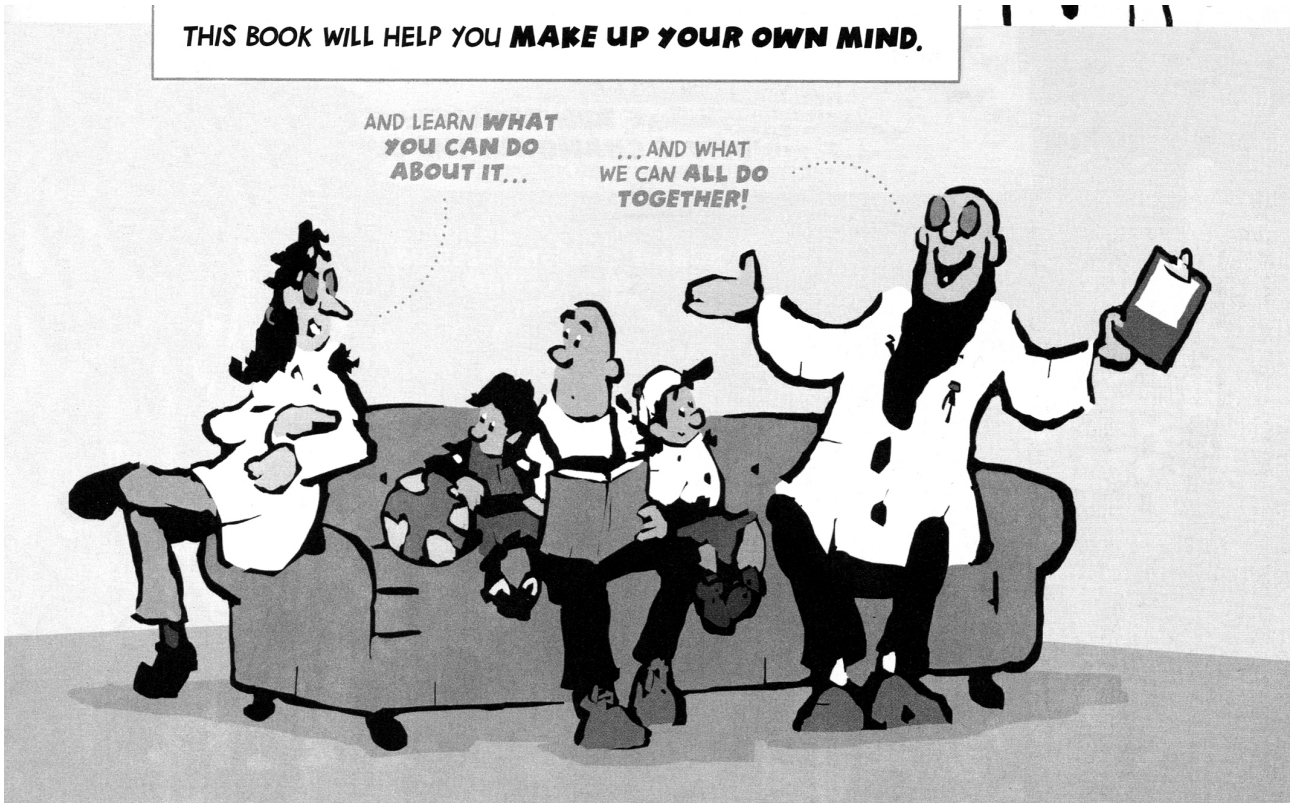


**Figure 9: Scientist characters setting a positive mood at the beginning of CICC.**

Most science texts try to be as objective, emotionless, and unbiased as possible in order to not disturb objectivity. CICC, however, has clear changes in its mood. These changes are mostly realized through the narration and the verbal mode while the images support the messages. The message of the book is grim – if we do not act soon, the humanity and the planet may be doomed – but the reading experience is light. This is because the book is skilful at regulating readers' emotions: first it makes the reader feel concerned and scared for the well-being of their own, then of the people they know, then the whole of humanity, and finally of the planet, then soothes these fears at the end. The hopeful mood is set by the scientists on page 9 (Klein & Bauman, 2014; see also figure 9): after explaining what the book is about and showing how politically charged and difficult to solve the issue is, the scientists sit down with some other characters, smiling and ready to educate: "learn **what you can do about it**... … and what we can **all do together!**" (bolding original). A character who hears of the bleak predictions for the future says, "I'm scared. What can I do?" (Klein & Bauman, 2014, p. 130) which is exactly what the reader is probably feeling at that point. Then the book soothes these fears by suggesting actions and giving the reader the responsibility and power to continue research and initiate a change in the society: "Ok, but what can **we** do?" ask some children (Klein & Bauman, 2014, p. 191, bolding original). The narration answers: "You can help by dreaming of a better future... [--] … and then working to **make it**

**happen**" (Klein & Bauman, 2014, p. 192, bolding original). This transfer of power is also shown visually when one of the scientists gives writing tools to some of the children. By the time the reader finishes the book, they are feeling hopeful. Preaching apocalypse stories may inspire people into action, and such narrations may find a receptive audience, but such an approach is hardly suitable for a book targeted at children and teenagers. Moreover, because solving the environmental crisis demands action and not passivity and apathy, it is fitting that the book attempts to encourage the reader to take action. I link the general positive attitude of CICC and its potential effect on its readers' mind sets to the improves attitudes found in previous research on science comics.

In CICC, scientific terms are often replaced with colloquial language or shorter terms, for instance, sulphur hexafluoride is referred to only as $SF_6$. Writing out the entire long chemical term every single time it appears would be cumbersome for both the letterer of the comic and the reader. The characters are also helpful in "translating" scientific language into colloquial language, for instance, one of them offers "wiggles and jiggles" as a translation for "eccentricity and precession" (Klein & Bauman, 2014, p. 31). Sometimes they provide both the scientific term and the colloquial term: "Scientists call them glacial periods. Everyone else calls them ice ages", and *ice age* is the term that is used most often from that point onward in the book (Klein & Bauman, 2014, p. 25). I find this to be effective in several ways: first, the creators slip proper scientific terminology in between engaging narration, thus ensuring that the reader knows the accurate scientific terms, and second, they avoid making the reader confused by using the colloquial term everywhere else in the narration. The latter point also helps the reader to connect the facts to their previous knowledge and experiences – even if it is only knowing what kind of movement wiggles and jiggles are. Thirdly, such translations evoke amusement; after all, such an unscientific and inaccurate expression as "wiggles and jiggles" is uncharacteristic of both a science text and a scientist. Following Propp's (2009) findings of humour, both – the book and the scientist – deviate from the norms of the groups that they belong to, surprising the reader and causing amusement.

Some jokes in CICC, especially verbal ones, contain structural incongruity, and the reader can resolve the incongruity with information that is available elsewhere in the comic (Zanettin, 2010). An example of this is the first panel on page 72 (Klein & Bauman, 2014, boldings original):

The text box says: "Of course, it's always possible that all those scientists are **wrong**."

A scientists says: "Whoops, **global warming** is actually caused by **broccoli**..."

This joke would not be half as funny if broccoli was a random thing mentioned in the book for the first time. But the reader has already encountered broccoli in the book: much earlier, on page 17 (Klein & Bauman, 2014), the same scientist proudly holds a plant pot in his arms and declares,

"[photosynthesis] turns **sunlight, water,** and **carbon dioxide**... into things like **broccoli** and **bean sprouts**" (bolding original). Also, this is the only time we read about broccoli in the book, which is not surprising because it has nothing to do with climate change. Mentioning it again much later as a cause of climate change is surprising and humorous in its absurdity because broccoli has an insignificant role in both CICC and climate science.

CICC contains many intertextual and cultural references in order to keep the reader engaged. Sometimes well-known utterances or slogans are utilized in new and surprising contexts, and this causes amusement. For instance, on page 18 (bolding original), one of the scientists says "You **are** what you **eat**!" after seeing that there is carbon in almost everything – in the plants a cow eats, in the cow, and in the milk and burger meat that humans consume. "You shall not pass!", an exclamation made famous by Gandalf the Grey in the movie *The Lord of the Rings: Fellowship of the Ring* and shrieked by $H_2O$ (Klein & Bauman, 2014, p. 96; see figure 10) is another example. The exclamation is fitting for the scene because $H_2O$ is blocking the energy radiated by Earth from leaving the planet's atmosphere. It is also an example of a non-human character acting like a human which is often considered humorous (Propp, 2009). Moreover, the scene where a detective has arrived to investigate a murder and inquires what has happened is a parody of a situation often seen in detective stories, only here the answer to the question is unexpected because the scientists begin to recount the history of the Earth. Either they have misunderstood the question or they deem everything in the history of the planet important in regards to knowing what led to the murder. Propp (2009) says that parodies are a form of comic and Zanettin (2010) mentions that editorial cartoons often use parody. Since the page where the detective parody takes place is a title page for chapter two and is therefore isolated from the main narration, it can be considered a single-panel cartoon that follows the rules of cartoons rather than those of comic books.

The jokes in CICC use the ambiguousness of words and phrases for their advantage. For instance, when one scientist says, "[green things] pumped lots and lots of **oxygen** into the atmosphere", organisms can be seen to be breathing bubbles from their mouths towards water's surface – and next to them is Harriet who is enthusiastically pumping air into another organism with a bicycle pump (Klein & Bauman, 2014, p. 19, bolding original). This is an example of how wordplays get a new meaning when they are paired with an image (mentioned by Zanettin, 2010). Wordplays are also constantly used by the single-celled organisms in their own jokes. The jokes are not very good, and the creators of the comic acknowledge this fact by making Harriet say "You and your jokes are so **primitive**!" which is a joke in itself because the organisms as life-forms are primitive (Klein & Bauman, 2014, p. 16, bolding original). Sometimes these wordplays are not

amusing because of the image that they are paired with but because of the context. For example, when it is time to start talking about fossil fuels, a joke provides a smooth transition: in three subsequent panels, we see two organisms lying in what can be deduced to be earth, going deeper into earth in every panel, cracking a knock-knock joke (Klein & Bauman, 2014, p. 23, bolding original):

"Knock knock"

"Who's there?"

"**Oil**."

"Oil **who?**"

"**Oil be back.**"

The joke is a reference not only to the oil that the organisms will become, but that the oil will be digged up eventually – "I'll be back." – and used as a fossil fuel. "I'll be back" is also a famous movie quote from the *Terminator* movie. This example shows how the different modes and signs and the various meanings found in them affect the reading and interpretation of a text, that is, the joke.

Another example of wordplay can be seen in the use of adjectives and descriptions. For instance, one of the scientists is holding slime in his hand, and since we know that slime could be described as gross, it does not come as a surprise that the scientist starts saying, "Green slime is gross"; however, the comment turns out to be "Green slime is **grossly** unappreciated" (Klein & Bauman, 2014, p. 19, bolding original). In this way, things can be commented on in a humorous

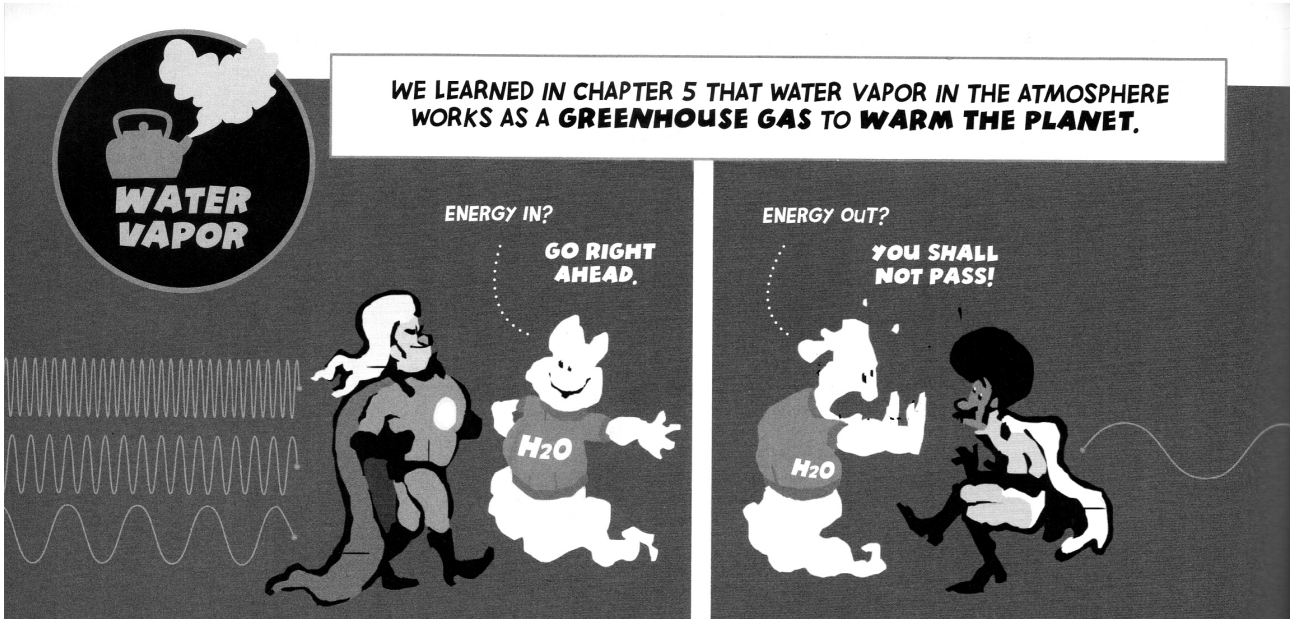


**Figure 10: A famous movie quote in use in CICC.**

way while also subtly emphasizing their importance in a certain context. I believe that this is an effective alternative to writing long sermons about their importance, especially in a context where readers are probably not interested to read any more about green slime or things alike. However, an amusing comment such as this one may stick in the reader's mind and make them re-consider their attitude towards slime and other unappreciated things.

Narration in science comics may increase engagement, interest and comprehension (Tribull, 2017; Jee & Anggoro, 2012). In CICC, there is not only one overarching story but several small ones that span a couple of panels, a spread or several pages. As Jee and Anggoro (2012) suggest, the narratives follow the pattern of our everyday experiences: an event occurs, events take place in a temporally sequential order, there are actors and objects, and the events usually have a beginning, a middle, and an ending. Similar pattern can be seen in scientific research reports – they take the form of a recount where events are presented in a temporal order (Kress, 2003). Situated learning model is also in favour of narrations because they ease the effort of communicating, remembering, and recalling things (McLellan, 1996). The book itself starts with a textbox saying, "Two stories are going to dominate the 21st century" (Klein & Bauman, 2014, p. 3), and these two stories are economic growth and the environmental impact of this growth. Therefore, narration is acknowledged to be a major part of the comic book.

Because narration in science comics has such a great role in both science communication and entertainment, it is worthwhile to explore the stories in CICC further. Even though traditional stories – a hero/protagonist goes on a mission and, in the end, achieves their goal – are not a part of the narration in CICC, there are clear elements of stories: the current, dire situation is revealed to the reader and past events are explained as well as the chain of events that have resulted in this situation. There is a narration and omniscient narrators – namely, the scientists. The cast of the story is introduced, and conflicts arise from the interactions of the actors: greenhouse gases interact with solar energy in one way and in another way with the energy emanated by Earth. In the end, suggestions for resolving the conflict are given and we get to see the future, or multiple alternative futures, that depend on the actions of the humankind. It could be said that, at the end of the book, the mantel of the hero is passed on to the reader whose task it is now to go on a mission and save the planet.

In addition to the overarching narration, each of the chapters is dedicated to describing one larger topic. Often, one chapter-long story is used to explain a topic. For instance, chapter two narrates the story of Earth: the whole chapter is a sequential narration of the evolution of life and the atmosphere and their effect on the climate. Chapter three, on the other hand, begins with an

account of long-term changes in climate and the birth of ice ages before showing how these phenomena have affected life on Earth through the lives of two cave-dwellers. There are, however, very short narrations that are connected to wider narrations: for instance, the comic explains the importance of snow and ice as a reservoir of water, and for three panels, we can see how the lack of snow and water affects the life of a gardener who is not able to water their plants (p. 95).

Even though each chapter focuses on its own topic, there are verbal and visual bridges that tie the chapters and narration together. For instance, on the last page of chapter one, the hot-air balloon where the scientists and two children are traveling moves from left to right, according to the reading direction of the comic, and guides the reader's eye to the next page, encouraging the reader to continue reading. In addition, lexical coherence ties the ends together: one of the scientists says, "Let's start to answer it by taking a brief look at the **history** of **planet Earth**" (Klein & Bauman, 2014, p. 14, bolding original). The name of the next chapter uses the same words as the last speech bubble of the preceding chapter: "A brief history of planet Earth". Also, the familiar scientist characters are drawn on almost every chapter cover page, and in this way unify the narration and keep it from feeling like a collection of separate short stories.

The present and the previous chapters have dealt with the separate visual and verbal modes of CICC. However, as has been seen in some examples, an analysis of the interplay of the modes is required for an understanding of, for instance, humour and entertainment. The next section will examine the multimodal combination of the modes: the comic form.

### 4.3 The comic and multimodality: the combination of the visual and verbal modes

Comics is a multimodal medium. Different modes should be used where they best serve their communicational purpose: writing can be used for recounting events, and images are best used for displaying pictorial presentations of entities and their aspects (Kress, 2003). In comics, the combination of the modes renders possible the tehnique of "show and tell" (McCloud, 1994). In science comics, it is useful to both verbally tell the reader what is happening during natural processes and show the processes visually. Alternatively, wherever applicable, events can be only shown or only told. As was discussed earlier, "show and tell" is also used in comics to provide perceptual experiences that are out of reach in typical learning settings, such as homes or classrooms, and with typical educational materials, such as traditional text books. "Show and tell" also produces the figurative fieldtrips and "social" and "physical" learning environments (with the comic characters) that are important in situated learning.

In CICC, many instances that take advantage of "show and tell" in order to provide perceptual experiences can be found. These instances include written descriptions of the theories behind phenomena and visual depictions of characters who act according to the theories, telling the reader about possible futures and future events and simultaneously showing them as images, hence explaining new concepts both verbally and visually. In principle, the narration in CICC can also be grouped into "show and tell" since the narrations rely on verbal explanations and visual depictions of events. Moreover, in CICC, "show and tell" is a way to adapt science content into the comic form: the visual depictions add a second layer on written scientific explanations and, hopefully, clarifies the explanations and eases the comprehension of material, which in turn makes the learning experience more enjoyable.

An example of "show and tell" in CICC is the explanation of energy: how energy comes from the Sun to Earth, how some of it is blocked by the atmosphere, and how Earth emits some energy, too (Klein & Bauman, 2014, pp. 53–58; see appendix C). We as humans cannot see this transmission or the courses of energy with our plain eyes, so in order to help the reader comprehend the phenomenon, the creators of CICC have decided to visually show the courses of the energies

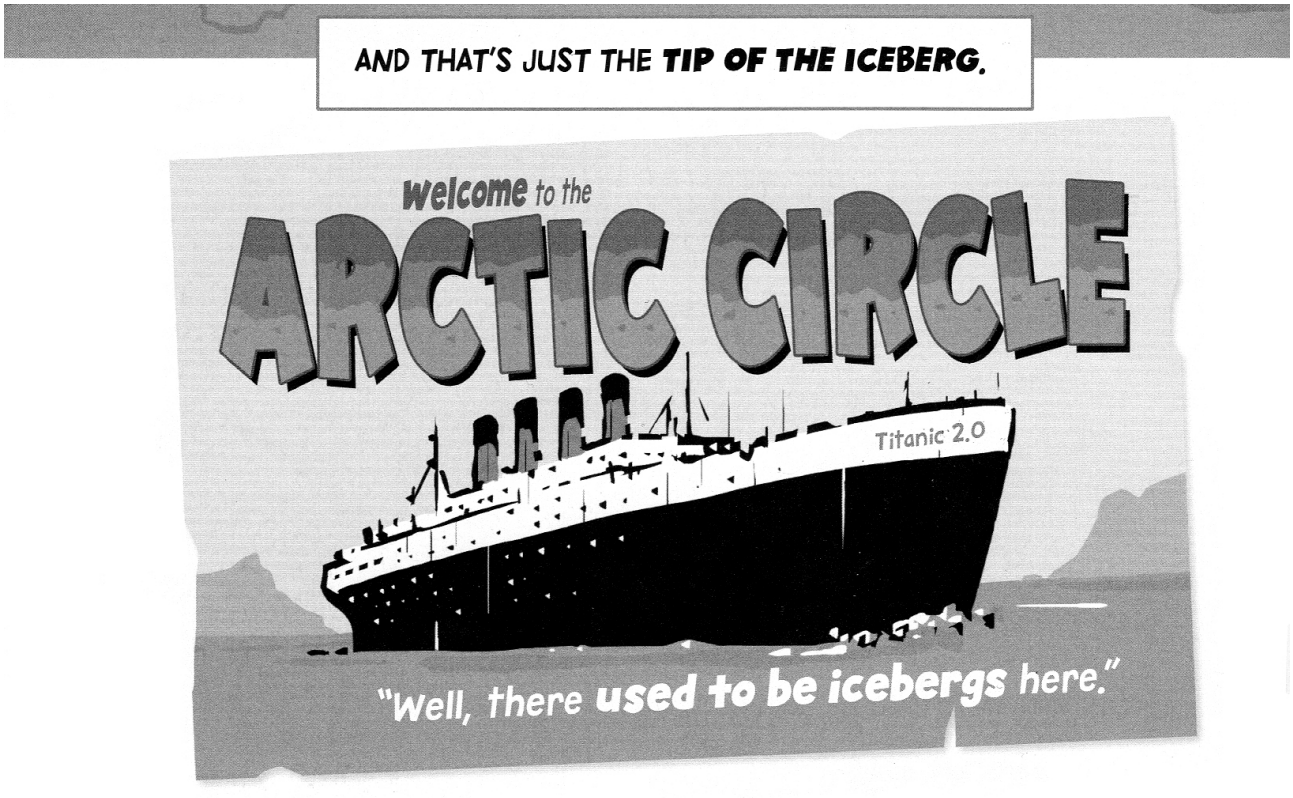


**Figure 11: An illustration of a postcard depicting a possible future of the Arctic Circle.**

both in space and in Earth's atmosphere and verbally tell the progress of events. Another example is showing the consequences of global warming: instead of listing different areas and countries and the changes in their environments, the creators have decided to take a creative route and show the environments in illustrated tourist postcards (Klein & Bauman, 2014, pp. 86–87). The postcards read, for instance, "Welcome to the Arctic Circle. 'Well, there used to be icebergs here.'" or "The world's deserts – now even bigger and drier!" (Klein & Bauman, 2014, pp. 86–87, see also figure 11). In another example, when explaining how global warming turns snowfalls into rain, CICC shows three skiers in distress on a snowless mountain top instead of verbally reminding the reader that they could no longer enjoy winter activities without snow (Klein & Bauman, 2014, p. 95). Similarly, definitions for such concepts as climate and weather (Klein & Bauman, 2014, p. 13) are shown and told by connecting them to relatable everyday events: the written mode provides the definition and the visual mode the real-life example. Defining concepts in this way is more accessible to the reader than reading only written descriptions with strictly scientific terms because presenting a scientific description in a dialogue and/or a narration helps some learners comprehend it more easily (Lin & Lin, 2016). Therefore, studying descriptions of this kind make learning more enjoyable, at least for some learners.

The comic form makes it easier to understand temporal and spatial changes, processes, and cause-and-effect, simply because images are placed in juxtaposition and the reader is able to see processes with their own eyes. The perceptual experiences that science comics provide through descriptions and illustrations improve learning as has been pointed out by Jee and Anggoro (2012). Also, as Tatalovic (2009) points out, it is easy to compare the before- and after-pictures in comics and thus deduce what has changed and to understand the process. In CICC, the temporal and spatial changes are visible in how the comic takes the reader back and forth in time and from one place to another. For instance, whereas chapter one is focused on recounting the current situation, the first scene of chapter two takes place 4,6 billion years ago, and the chapter continues to depict sequential events that occur millions of years and thousands of kilometres apart or events that are completely imaginary. Due to this, in CICC, the transitions from one time or place to another are great and often sudden, and the transitions would not make sense if the contents of sequential panels were not connected to the same topic or if the connections were not described verbally. Only rarely are there instances where one event is narrated across sequences of panels, such as when a character comes to ask one of the scientists what will be the average change in global temperature and the scientist is unable to give a definite answer (Klein & Bauman, 2014, p. 83).

Cause-and-effect is visible on page 6 (Klein & Bauman, 2014) where the upper panel is full of vehicles and factories, and the river that flows at the bottom of the panel pours into the lower panel as a waterfall of garbage, illustrating the downside of technological advancements and the pollution it generates. Chains of events also become apparent, for instance on page 18 (Klein & Bauman, 2014) where the progression of water and carbon in the food chain is illustrated: in a panel are depicted, starting from left, a pot of plants, then a cow that is eating the plants, and lastly a farmer who is milking the cow and a child who is holding a hamburger. Under each of these events is a placard that reads "Mostly Water and Carbon". Juxtaposed panels also aid at comparing different situations because the reader is able to see them side by side and compare what the different situations look like and find the differences in them, in a sense seeing the processes "in action". An example of this is how climate change affects the rich versus the poor: the page has been vertically divided into two, and on the left side we see the problems of the rich and on the right side the struggles of the poor in the same situation (Klein & Bauman, 2014, pp. 108–109). When the sea levels rise, a rich person is shocked to find out that their summer home has become flooded whereas a poor person loses their whole farm to the flooding sea. Because we cannot see into the future and the outcomes of the climate change, the potential environmental destruction and the resulting human suffering, CICC takes us forward in time and shows them to us.

Panel-to-panel transitions require a clear reading path to follow. In CICC, the reading path moves from left to right and up to down and is constant and straightforward, which makes reading the book fast and easy. There are relatively few panels per page, and they are arranged in the same way, usually three or four panels placed in three rows on a page. Similarly, even though panels are at times rather cluttered with distracting details, the arrangements of textboxes, speech bubbles, and key characters create a reading that is effortless for the reader's eyes to follow. As was discussed earlier, the narration benefits from the reading path and left-to-right movement on the page, and so does the reading itself. Lin and Lin (2016) call for clarity in science texts, and I believe that science comic creators can ensure the clarity of their comics by paying attention to visual composition. After all, if the reader is confused by the arrangement of speech bubbles and panels, learning new science content may become too challenging. However, with CICC, the reader does not need to guess which part of the page or a panel to read next and can enjoy the learning experience uninterrupted. In this way, the comic adheres to the conventions of comics, ensuring an uninterrupted flow.

In CICC, natural phenomena and scientific theories have been connected to readers' everyday lives, which is in accordance with the theories of science communication, the situated learning

model, and the findings from research on science comics. When describing reactions and phenomena, illustrations and the narration provide analogies and contexts that the reader can link to their previous experiences. Abstract phenomena and theories are linked to familiar real-life events: for instance, the feedback loop explaining the birth of ice ages is linked to musical bands, microphones, and amplifiers (Klein & Bauman, 2014, p. 32). Many of us have experienced, perhaps multiple times in our lives, the event when someone is talking in a microphone on a stage, and suddenly there is a high howling noise that starts to increase in volume. This is caused by the microphone picking up the sound from the amplifiers, and the amplifiers amplify the sound, which will be again picked up by the microphone and amplified by the amplifiers, and so forth. The creators connect this familiar experience to the theory of the feedback loops in climate. The analogy is especially fitting because both the musical situation and the scientific theory can be explained using the same vocabulary (rhythm, loop, to amplify). Sometimes even a familiar, domestic setting can give the reader the right mindset to interpret events and processes, such as first reading what liquid, solid, and gas water are and how they behave in the domestic environment before learning how they connect to theories of climate change (Klein & Bauman, 2014, p. 91).

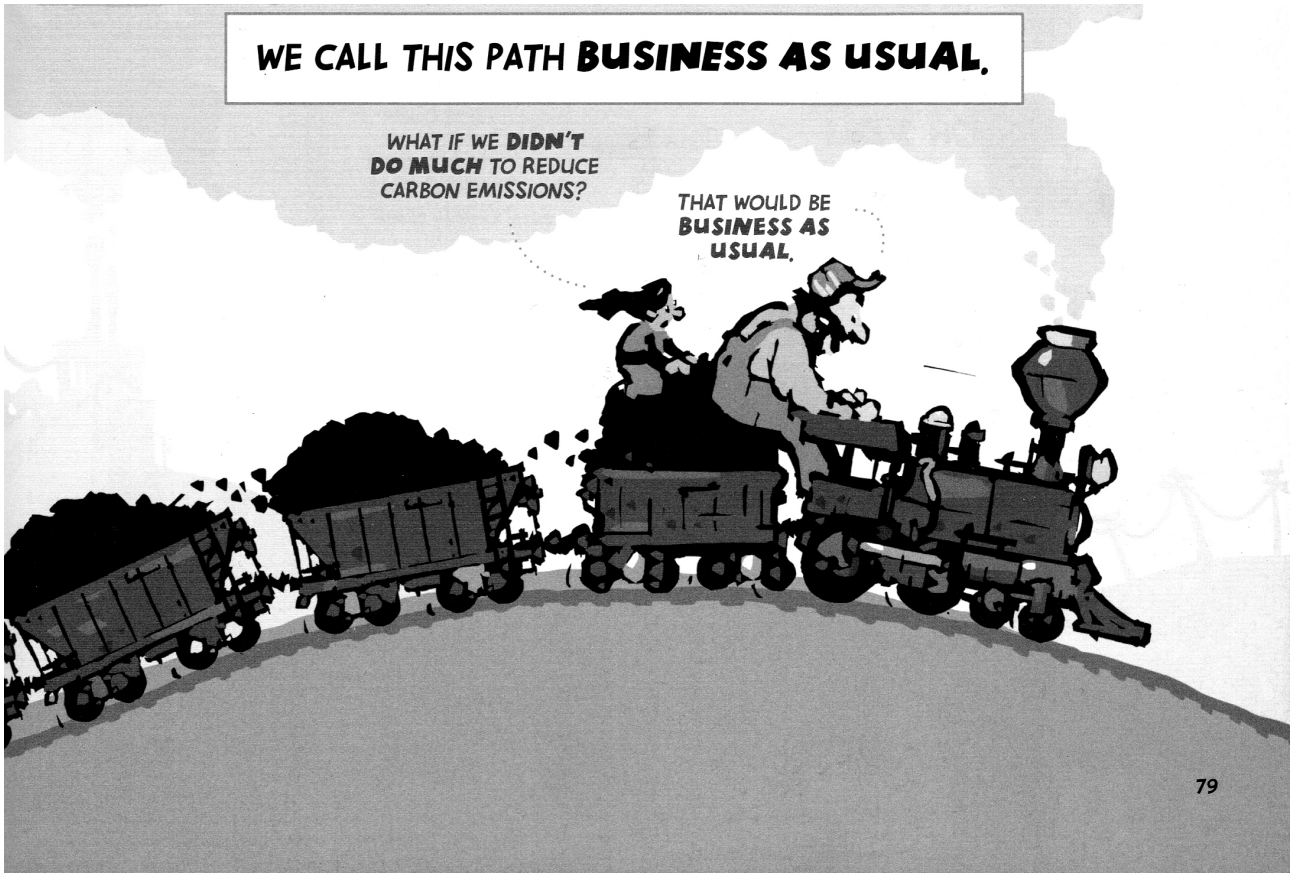


**Figure 12: ”Business as usual”.**

Perceptual experiences are also present in the explanation and discussion of the key concepts of the comic book: they are visualized in order to make them tangible and the comprehension of them easier. Examples of these concepts are “business as usual” which has the form of a moving train with a varied number of passengers straddling on it, “subsidies” which are depicted as balloons, “carbon taxes” which look like large dark wrecking balls, and “cap and trade” which is an equally large and dark cube. The visualizations have not been chosen arbitrarily; the concepts have similar effects and they behave in the same way as their object-counterparts. “Business as usual”, which the creators explain as the humanity continuing polluting the atmosphere and environment as we have been until now, is a vehicle that simply chugs forward with seemingly no one to regulate its speed or direction and its cars loaded with coal, a fossil fuel (see figure 12 for an illustration). Visually, the train's movement always goes from left to right on the page, following the Western reading direction, and it is occasionally stopped by other personified forces, such as clean energy (Klein & Bauman, 2014, p. 149). The train's most alarming trajectories take place on page 129 when it plunges off a bridge – a metaphor for the destruction of the industrialized world's living standards – and on pages 134–135 (Klein & Bauman, 2014), when it is headed directly towards the planet Earth that has been placed on the train tracks, a passenger uttering “Somebody's got to do something... Right?” This is a metaphor for and a reminder that “business as usual” will very likely wreck the planet, and a metaphor of the inability of the humankind to take responsibility, make effective changes in our societies, and “save” the planet.

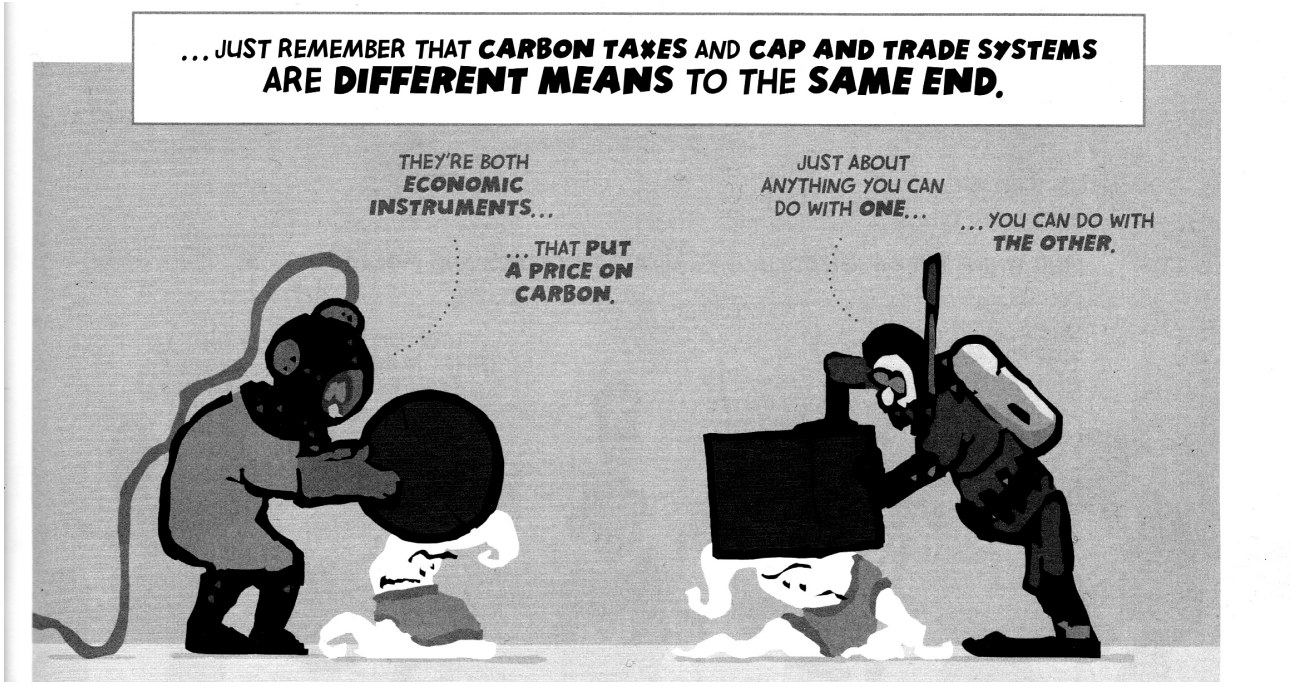


**Figure 13: A panel depicting the similarities between carbon taxes and cap and trade systems.**

The other visualized concepts create visual analogies also. When fossil fuels (depicted as miners) and clean energy (depicted as superheroes) are placed on a see-saw, with the fossil fuels in the air and clean energy on the ground, “subsidies” can be used like balloons to balance the situation by lifting the end of clean energy (Klein & Bauman, 2014, p. 154). (I will discuss the visualization of invisible entities in chapter 4.4 Characters.) Similarly, “carbon taxes” and “cap and trade” can be used as weights to lower the fossil fuels' end (Klein & Bauman, 2014, p. 156). Moreover, placing them as weights on planes and cars and on top of factory pipes tells the reader the concrete effects of taxes on industries: many planes will stay on the ground and factory pipes will stop puffing out pollution. The objects are also used to visualize how costs of taxes can be forwarded from one actor to another simply by passing a large, heavy ball to another person; similarly, giving the polluting industries one large ball enables other fields to throw smaller balls away, an analogy of how making the industries pay more taxes and giving the other fields tax reliefs works (see figure 13 for illustrations of these). Also, the convergent appearances of “carbon taxes” and “cap and trade” suggest even without reading that the two approaches are in some ways similar. As Walch mentioned in the interview and as previous research on science communication, science comics, and situated learning imply, visual analogies help readers understand abstract concepts, and I think that CICC uses visual analogies extensively and effectively for this purpose also.

Besides giving intangible things a visible and active form, the creators have turned many passive reactions and processes active as well. Rather than showing or explaining how they happen slowly over a very long period of time, active forces contribute to the reactions and processes in CICC. Examples of this include penguins compressing snow on polar regions by treading on it (Klein & Bauman, 2014, p. 28), and Harriet the single-celled organism suddenly “figuring out” how oxygenic photosynthesis works, shouting “Eureka!” like Archimedes and jumping out of its bath (p. 17); and greenhouse gases directly interacting with energy radiation either by telling the superheroes to pass through or by blocking them with words and gestures. These implications of change can be quite subtle: the slow acidification of oceans is depicted by a scientist holding a bucket and walking on the pH scale from the natural, neutral pH value of sea water towards the acidic end of the scale (Klein & Bauman, 2014, p. 98). In these ways, processes and phenomena are turned into comprehensible, visual metaphors. Comics inherently utilize before- and after-images that can be used for illustrating steps in a sequence of events (Tatalovic, 2009) so comics as a format is a suitable tool for explanations of reactions and phenomena. The audience of the comic is in some ways visible in the selection of these contexts: for instance, the intended reader is someone who connects a white gown and veil to a wedding, and has sufficient knowledge of polar bears to

understand how they are linked to climate change and adaptation. Successful metaphors increase the enjoyment of and gratification received from the content while failure to connect the dots between the analogies, theory, and one's life results in frustration and misunderstandings, thus diminishing enjoyment.

Many different icons are used in the comic to improve both the comprehension of content and the reading experience: the comic utilizes different markings to communicate a scientifically significant movement, activity, or a property of an object. For instance, the reflective attribute of an object or element is signified by a V-like mark. Some of the icons are regularly used in comics, such as a halo of wavy lines to signify warmth emitted by an object and lines that differ in length and curvature to suggest different kinds of movement. Sometimes an icon becomes a permanent property of an object, distinguishing it from other similar objects: as the narration progresses, the planet Earth that the characters keep with them is increasingly shown with undulating lines around it, implying that hotness has become its property. Markings are also used to direct the reader's attention to desired places, such as the highest points of a graph's curve that are accompanied by small rays that seem to fly out of the peaks (Klein & Bauman, 2014, p. 29; see also figure 14). Icons for liquid water, solid water, and water vapour help distinguish from each other the different sections dedicated for each respective subject (Klein & Bauman, 2014, p. 91–98). Also, because the icons visually depict the different forms of water, it is not necessary to verbally explain what the different forms are. Signs can also be subtle depictions of natural phenomena, such as photosynthesis: a scientist puffs air on a plant she is holding in her hand – this can be inferred from the lines in front of her mouth (Klein & Bauman, 2014, p. 17). At the same time, similar lines signify that something is emanating from the plant. Because the narration is at that point explaining the theory of photosynthesis, it can be deduced that this event depicts photosynthesis occurring in practice.

Arrows signify change and movement, and they are used abundantly in CICC. Even though in the comic form, movement can be presented by showing the images before and after the movement in subsequent panels, movement can occur within one panel also, as has been noted by McCloud (1994). In these cases, arrows become useful because they can be used to show the direction and course of an object's movement. For instance, the rotation of the Earth around the Sun can be presented in this way (Klein & Bauman, 2014, p. 30); because the starting and ending points of the cycle are the same, arrows are exceptionally useful and, I would argue, more effective at showing the movement than through a panel-to-panel transition. Through their size difference, arrows have been effectively used to signify difference in amount in CICC: for instance, because plant-related

carbon cycle is 120 billion tons per year and seawater-related carbon cycle equals to 80 billion tons per year, the arrows that show the direction of the carbon emanated by plants is larger than the ones showing the progression of carbon from seawater (Klein & Bauman, 2014, p. 18). In addition to arrows, other signs can be used to denote movement, such as curling lines to depict wind, and the strength of wind can be visualized through the size and thickness of the arrow (Klein & Bauman, 2014, p. 14). These are some of the ways in which the comic form enables the creators of CICC to present the movements of objects more effectively than with linear text or single illustrations only. However, even though icons and arrows of these kinds are well-known to comic fans, they may be confusing for an unacquainted reader and hinder reading or even cause misunderstandings, thus diminishing their enjoyment of the comic.

The science content in CICC remains coherent and focused on climate change throughout the book, and the reader is occasionally, when necessary, reminded of something they have learned in the book previously. Characters often refer to and remind of previously learned theories by saying directly “go to page x”. When the characters refer to them visually and/or verbally, perceptual experiences and analogies become useful again. The reader is not expected to remember a theory, such as the feedback loop of climate change, solely from reading about it once. For example, when there is a reference to the feedback loop at the end of the book, the circular diagram that the reader has seen previously is shown with new illustrations and a scientist character emanating heat and screaming into a microphone, “**Warming** turns into **even more warming**” (p. 177, bolding original). The diagram reminds the reader of the analogy that was presented earlier in the book when the theory of the feedback loop was explained, and in the case that the reader does not remember what the meaning of the diagram is, the scientist's comment clarifies the core idea of the theory. Also, for instance, a character comically reminds the reader of the ice-albedo effect, a phenomenon where Earth's glaciers reflect the solar energy back to the space, by saying “It's albedo!” and pointing at his bald and reflective scalp. These references are sometimes coupled with visual markings, such as the aforementioned V-like sign that implies reflection; this mark is used both when the comic explains the ice-albedo effect and when one of the scientists refers to the effect later on in the comic. The character does not need to mention anything about reflections – the icon does it for him. These reminders help the reader comprehend the greater picture of climate change and the phenomena that are connected to it. Moreover, when using visual aids, there is less need for verbal explanations. Repeating past events visually is also a common storytelling technique in comics: either a character remembers an event from their past in a flashback or a visual prompt reminds the reader about an event that has happened earlier in the comic.

Psychology supports the notion that context is important for recalling: "[s]ince context is a powerful retrieval cue, we can improve our memory by restoring the context in which the learning took place" (Nolen-Hoeksema, Atkinson & Hilgard, 2014, p. 296). Using a physical learning setting as a retrieval cue is effective for the recollection or learned information, and it would seem plausible that the effect is the same when restoring the visual context seen in a comic book. Every time feedback loops are mentioned in the book, the same circular diagram and the musician-scientist are attached in the proximity of the text to remind the reader of the context where they first learned about the feedback loops. Retrieval of information is an efficient studying method – that is, reading a text and then asking oneself questions about it (Atkinson, 2014). Sometimes, CICC does the questioning on behalf of the reader as characters' reapparances make the reader recall and remember where they have seen the characters before. Referring to previously learned theories and reminding the reader of them is typical of science texts and most likely increases the reader's comprehension and enjoyment of the material.

Because comics are a multimodal form that combines the visual and verbal mode, it is not irrelevant how drawings and written text are combined or how they relate to each other. As has been pointed out by e.g. Tribull (2017) and Jee and Anggoro (2012), the comic form removes some of the

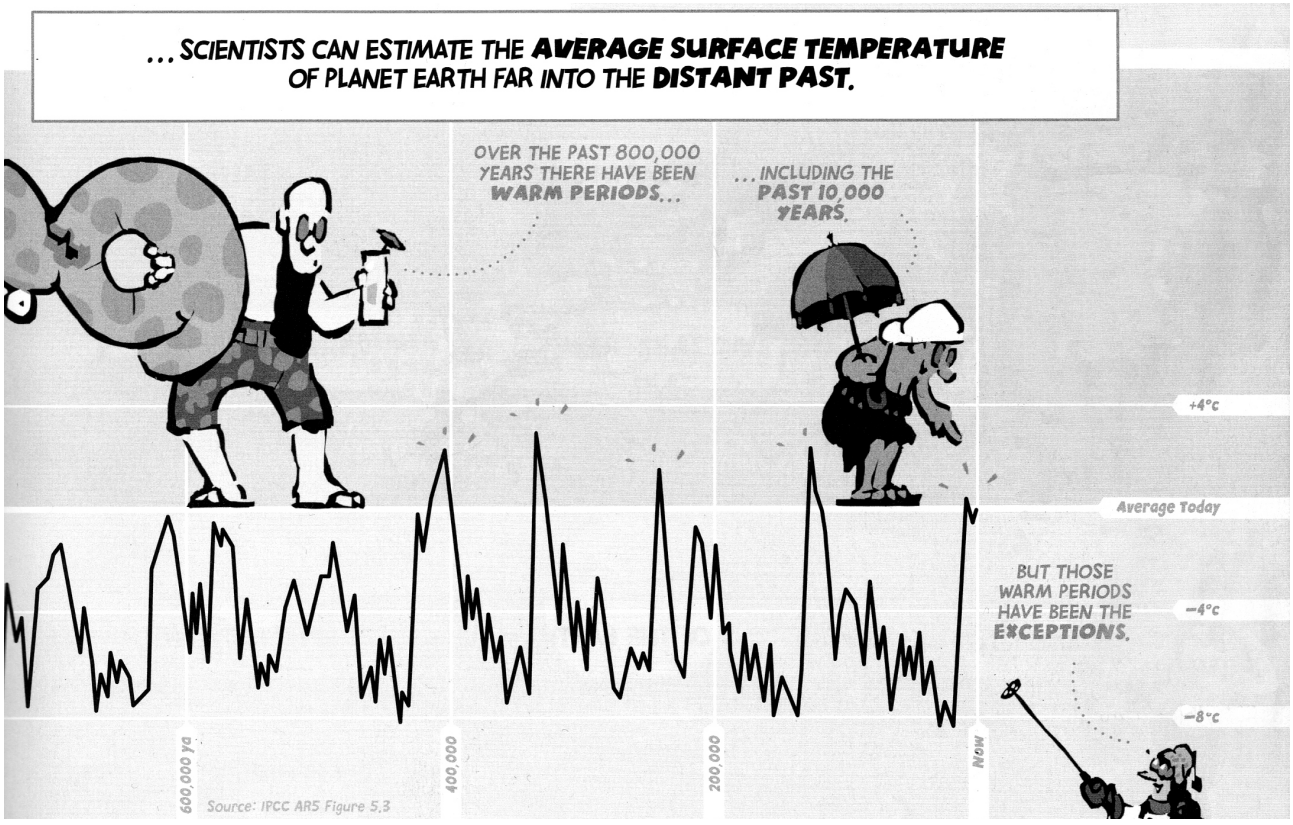


**Figure 14: Written text integrated into an image in CICC and highlighted peaks in a curve.**

challenge of reading science content by integrating words into pictures and allowing the reader to read visual and verbal text side by side. According to Jee and Anggoro (2012) science comics employ three kinds of text: narration, speech and thought bubbles, and sound effects. In CICC, there is abundantly narration in the textboxes and dialogue in the speech bubbles. The textboxes introduce theories and concepts to the reader while speech bubbles link theories to real-life contexts, explain situations and add details; for instance, textboxes tell the reader that the tilt of the Earth causes winters and summers, and speech bubbles, integrated into a panel where characters float in outer space and observe the sun and the Earth rotating around it, explain how this works in practice (Klein & Bauman, 2014, p. 30). Not a single sound effect appears in the comic. However, there are plenty of other kinds of written text, for instance, the labels in greenhouse gases' shirts, or words that are used to introduce new terms of concepts, such as “OFFSETS” (Klein & Bauman, 2014, p. 179).

Yet another example of integrating words into pictures comes in the form of graphs: characters are drawn within graphs and they explain the curves or give additional information, sometimes even humorous commentary (Klein & Bauman, 2014, p. 42, p. 45; see figure 14 for an example). Moreover, sometimes, verbal text is transformed and incorporated into a drawing; for instance, on page 28, the text “Falling snow got” is drawn as falling snow, and “compressed trapping ancient air in ancient ice” is drawn under the snow (see figure 15 for the illustration). Playing with typography makes reading more memorable and makes understanding processes, such as compression of snow, easier. Also, the amount of text per page in CICC is consistent throughout the book: even though the comic contains a lot of verbal text, both in narration and speech bubbles, it is divided into small bite-sized portions to make reading lighter. This is a way to decrease the density of the science content and concurs with the views of Olivia Walch. Single textboxes and speech bubbles rarely consist of more than one clause or sentence. In some cases, they can be short remarks or exclamations such as “Giant ferns!” (Klein & Bauman, 2014, p. 23). As is done in many comics, the key words in each sentence are bolded, thus drawing the reader's attention to the words. The font used throughout the book is playful and cartoon-like, and its size varies depending on how much emphasis is placed on a sentence. These several factors ease both reading and the comprehension of science content and are another example of how to adapt scientific content to the comic form.

The textboxes, speech bubbles, and drawings are semantically linked together, and they are dependent on each other in regard to communicating the science content. The means of linking them are elaboration – “one clause restates or clarifies another”; extension – “one clause adds

information to another"; and enhancement – "one clause provides information such as how, when, where or how in relation to the other clause" (Jewitt, 2009, pp. 17–18). The speech bubbles in the comic both elaborate, extend, and enhance the content of the textboxes, and in some cases, of the drawings. For instance, a text box says, "But there are other human activities that add $CO_2$ to the atmosphere..." and a character under it extends the clause by exclaiming, "Like deforestation!" (Klein & Bauman, 2014, p. 172). Enhancement occurs on page 142 (Klein & Bauman, 2014), for example: a text box explains, "... and sometimes self-interest happens to coincide with emissions reductions." The characters in the adjoining panel comment in the following ways: "We want to clean up local pollution...", "... and improve energy security...", "... and burning less fossil fuels will help us."

Similarly, the drawings refer to the content of both the textboxes and the speech bubbles. For instance, on page 20 (Klein & Bauman, 2014), the narration explains that the birth of the ozone layer "allowed life to move into the sunshine", while Harriet, a single-celled organism, climbs onto the shore from the sea, unbothered by the rays of the Sun that is visible in the horizon. In other words, the panel contents in CICC provide information of the manner in which life moved into the sunshine although the depiction is not scientifically accurate. The textboxes, however, do not enter a dialogue with either the speech bubbles or the drawings; they act as independent narration. They could be separated from the rest of the content, and they would still effectively communicate the essential facts and theories. The primary nature of the textboxes in CICC is established visually by keeping their form clear, uniform, and distinct throughout the book: they are always rigid rectangles with pitch black text on a white background, so they can be easily discerned amidst the large grey areas of the panels.

However, even though the contents of the panels complement the textboxes, they are not mere illustrations; they add to the subject and create short stories that, in some cases, work even on their own. For instance, on pages 8 and 9 (Klein & Bauman, 2014), a text box introduces the topic by stating "Climate change is a politically charged issue..." It would be easy to illustrate this clause by drawing a crowd of adults shouting at each other in a conference room and to continue the topic by drawing the crowd eventually reaching an understanding in the next panel. However, the creators decided to make the arguing parties two children who stand on either ends of a sofa and call each other "denier" and "alarmist". Between them sits a third person looking confused and cradling the planet Earth in their arms. There is also a television in the picture, which presumably has given the children enough information to be able to call each other by such names. The following textboxes continue the narration of climate change and its status in the political discussion, and the adjacent

panels continue showing the quarrel between the children whose arguments always correspond with the contents of the textboxes. In this way, throughout the book, the textboxes introduce the wider context of a phenomenon while the panels distil the phenomenon into a single event by telling a relevant and relatable short story of characters who are in the midst of this event. This is "show and tell" also: the comic form makes it possible to show and tell several separate stories at once and thus gives dimension and depth to the narration. The textboxes do not directly narrate the contents of the panels; the panels follow and comment on the textboxes but may also slightly diverge from the narration. Only occasionally do the textboxes react to the events of panel: for example, a textbox says "Getting oxygen ($O_2$) into the atmosphere was really important because...", and because it is interrupted by the events of the next panel, the next textbox continues with a repetition, "... because it led to the creation of a layer of ozone..." (Klein & Bauman, 2014, p. 19).

In the Western society, verbal text is used to interpret the image and to impose meaning on it (Kress & van Leeuwen, 2006). Language and visual images cannot always illustrate the same things in exactly the same way (Kress & van Leeuwen, 2006) – for instance, the definition of ocean acidification is probably clearer and more unambiguous in the verbal than in the visual form – so it is justified to give them different duties in CICC also. In most cases, the textboxes in the comic could be read independently of the image and the message could still be understood. Meanwhile, the comic panels give context and visualize the information in the textboxes but would usually be incomprehensible on their own. Therefore, it can be said that the verbal text of the textboxes and even the speech bubbles are required for a correct and the intended interpretation of the images. Also, since many images can be interpreted in multiple different ways (Kress & van Leeuwen, 2006) and since CICC is a science text, it is crucial that verbal text guides interpretation and corrects or prevents misunderstandings. In a comic of some other genre where literate interpretations are not required, images may be given greater importance than verbal text.

### 4.4 Characters' roles in increasing engagement and the comprehension of material

Since characters can improve engagement (McDermott, Partridge & Bromberg, 2018), and because engagement leads to enjoyment (Sherry, 2004), it is worthwhile to include characters in a science comic. In CICC, the characters are also integral to the communication of science. They are treated as representatives of certain populations or entities and as vehicles for communicating information rather than as whole characters: their features are simplified and generalized as is the case in scientific visual presentation (Kress, 2003), and almost all are nameless, aside from the single-celled organisms and other anthropomorphised characters. The characters of CICC are delivered

through the modes of the comic but they also act distinctly from the modes – that is, their effectiveness or the reasons for using them are not dependent on or related to the modes only. It could be said that the characters are more than a sum of the modes that constitute them; they are not simply lines on paper and spoken lines in writing but a product of the comic mode specifically. Therefore, their analysis deserves a section of its own.

The most visible characters are a trio of scientists. They can be deduced to be scientists because they wear white lab coats and are often seen with writing pads and pens in their hands. The reader can follow them throughout the book; they demonstrate and participate in events and explain ideas either directly to the reader or to the other characters. The scientists also fix misunderstandings; in this way, the comic acknowledges the fact that the narration and explanations may cause misunderstandings and addresses the issue by giving the scientist characters the roles of teachers and making them correct the misunderstandings (Klein & Bauman, 2014, e.g. p. 50). Only one of the scientists seems to be a white man: the two others seem to be women, one younger, with a long, curly black hair, and the other old, with her white hair in a bun and her skin a slightly darker colour than the other two. Science comics should break stereotypes, especially of scientists, and

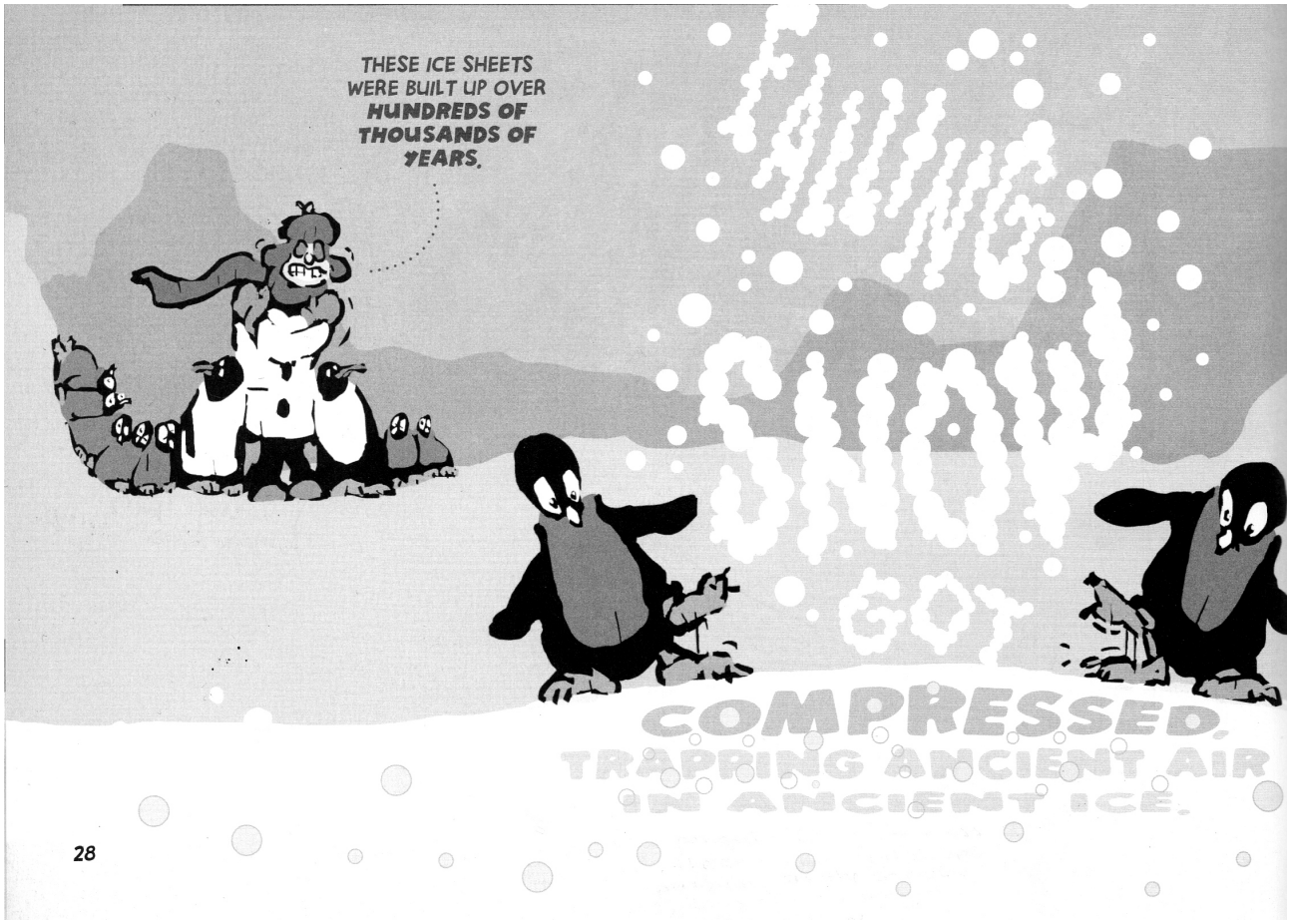


**Figure 15: Written text can be used as a part of a visual illustration.**

have diverse casts of characters (Jee & Anggoro, 2012), and by making its cast diverse and inclusive, CICC attempts to appeal to as many different readers as possible. The attempt for diversity is also seen in the cast of child characters in CICC: they are nameless and their features are simplified, so they are relatable to most readers. Young characters are present in the narration throughout the comic, and because the book's target demographic is presumably children and teenagers, I assume that the characters act as the reader's surrogates; they ask the questions the reader may have, such as "What's so important about [the ozone layer]?" (Klein & Bauman, 2014, p.19), and they are the ones to whom the scientists disclose the scientific information. The children, i.e. the reader, are taken on a journey with the scientists: to space in a hot air balloon to follow the formation of the Earth, to swim in pre-historic oceans, and to do scientific detective work in order to find signs of climate change. That is, the reader gets a chance to "experience" this all and interact with the scientists through the child-characters.

Whenever the characters are engaged in an activity while explaining scientific theories, the activity is closely connected to the phenomenon in question, or the phenomenon is essential at performing the activity – for instance, when textboxes inform the reader about the consistency of air, the scientist-characters assume yoga poses and say that there is an immense amount of carbon dioxide in every breath we take (Klein & Bauman, 2014, p. 40), and when the narration discusses growth in fossil fuel consumption, characters run eagerly forward carrying items that currently depend on fossil-fuel powered energy for manufacture and use (p. 136). The illustrations and speech bubbles that depict these situations connect the visual and verbal modes into the narration and help the reader find a connection between the scientific facts and everyday life. Characters react to the events of the book through their body language, facial expressions, and verbal communication, and they are emotionally invested in whatever their agendas are, such as the personification of green energy showing their frustration and yelling, "We need to get beyond fossil fuels!" (Klein &

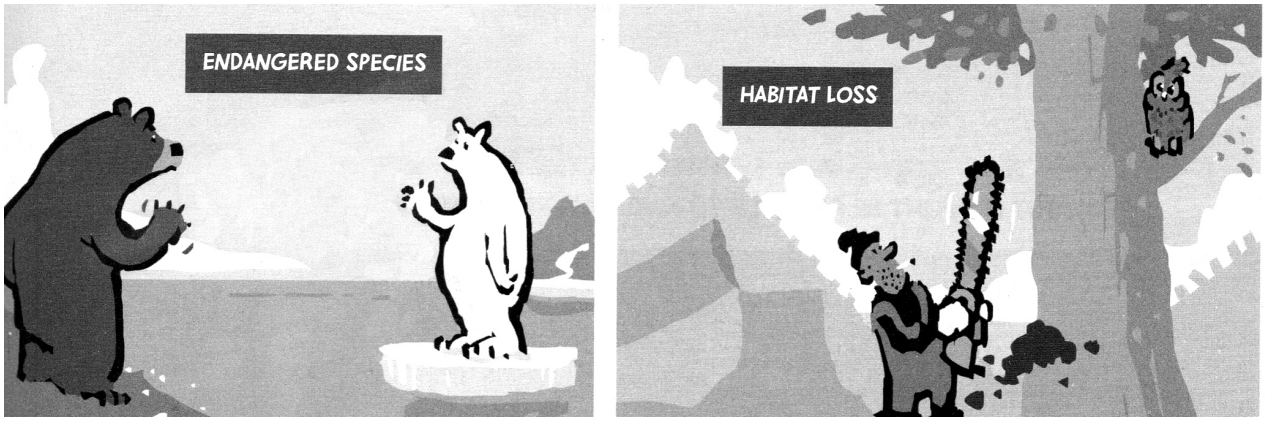


**Figure 16: Animals in CICC evoke amusement and emotions in the reader.**

Bauman, 2014, p. 171). These reactions guide the reader's understanding of situations: it is not necessary to always explicitly state that some phenomenon is harmful to the environment, animals, or humans because the statement can be inferred through the reactions of the characters. Also, following the characters' reactions and behaviour makes it easier for the reader to understand the motives and behaviour of certain factions or principles of a theory, such as different political and economic interests to either continue using fossil fuels or to decrease its use (Klein & Bauman, 2014, pp. 153–170). These ways to present information and consequences are different from how science texts typically present information. However, as Lin and Lin (2016) mention, dissecting facts and theories into dialogues and narrations may make learning easier. This approach of using characters' reactions to communicate information is also related to personification which will be discussed below.

The characters in CICC are sympathetic. The animal characters especially enliven the panels and make the reader think about the animals' fates in the human-centred world and rapidlychanging environments. Because the animals are often drawn quite small and it is difficult to interpret their facial expressions and emotions, the reader is free to impose whatever emotions they wish on them. For instance, an owl sits in a tree and watches a forest worker who is cutting down the forest (see figure 16); my personal interpretation of the situation is that the owl lives in the forest and it is horrified to see that its home is being destructed. The edge of the clearing is very close to it, so perhaps the tree it is perching on will soon be cut down, too. Also, many animals are given anthropomorphised appearances in the book as is often the case in science comics. None of them are given names but they behave in human-like ways, such as two bears standing on their hind legs and waving their paws at each other (Klein & Bauman, 2014, p. 7). Since personification makes it easier to relate to a non-human character (Jee & Anggoro, 2012), I assume that the creators have intended for the reader to feel empathy for the animals, impose human reactions and emotions on them, and think about the futures of all non-human animals, the innocent bystanders and victims of climate change. After all, polar bears, whom many know are in danger of extinction due to melting glaciers, get anthropomorphised forms in the section of the book that talks about adaptation. Imposing feelings on animals regulates the reader's emotions by arousal, thus contributing to the entertainment value of the book. Animals also invoke amusement through acting in human-like ways (Propp, 2009), such as the aforementioned bears waving at each other (see figure 16) or polar bears trying to adapt to climate change by donning on clothes and trying to live their lives as humans do (Klein & Bauman, 2014, p. 102).

Things that are invisible to the eye or extremely small are given visible, anthropomorphised, active forms and personal appearances, such as the primitive single-celled organisms (Klein & Bauman, 2014, p. 16), the energies respectively emitted by the Sun and the Earth (p. 54–58), and the greenhouse gases (e.g. p. 58). The organisms tell bad jokes, they have names, engage in domestic activities, and one of them even works as a teacher. They also have very human social norms: one of them is so shocked by another's "nudity" that it screams "Eek! Harriet, put on some clothes!" (Klein & Bauman, 2014, p. 17). The greenhouse gases sport their respective names (i.e. their chemical formulae) on their t-shirts, and their silhouettes, facial expressions, and body languages separate them from each other. For instance, on its first appearance, $CO_2$ looks smug and is flexing its arm while $CH_4$ looks slightly weird with its odd-coloured eyes and single tooth. Indeed, the details of the anthropomorphised characters have been given deep consideration. For instance, the energies are presented as superheroes in traditional tight suits and capes, but their clothes, skins and hairs are different shades of grey in order to distinguish them from each other. Moreover, the solar superhero is fatter than the Earth's hero, probably to visualize the fact that the Sun emits more energy than the Earth.

As has been noted earlier, personification has many advantages over other visual presentations: firstly, personification increases engagement with the narration (McDermott, Partridge & Bromberg, 2018); secondly, it makes characters more relatable, which in turn creates stronger memories; and thirdly, inferring the causal reasons behind the actions of non-human entities becomes easier (Jee & Anggoro, 2012). For instance, the reader sees the single-celled organism Harriet, how it deals with its companions' bad jokes, jumps out of its bath, and teaches a class of tiny baby organisms, and hopefully relates to Harriet's life and experiences. This, hopefully, leads to strong memories of not only Harriet and its life but also of the scientific facts that were explained using the epochal events in Harriet's life as examples. Also, reading the comic becomes a memorable experience when we see a superhero comically bouncing off of the Earth's ozone layer like a rubber ball (Klein & Bauman, 2014, p. 56). Moreover, the anthropomorphised greenhouse gases are more memorable and approachable than if they were presented as molecular models. The characters do not have to be exactly visually representative of how they appear in nature because the reader is not reading the book to learn about the biology of the organisms or the compositions of the gases but to learn how these things relate to climate change. Furthermore, I believe that personification helps the reader focus on the behaviour and actions of an entity rather than its appearance or other irrelevant questions; for instance, when perusing abstract drawings of invisible waves of energy that travel passively through the space may make a young or unacquainted reader

be caught in irrelevant questions, such as “why do the waves look like this?” or “how do the waves travel in a vacuum?” However, when looking at and reading about an active subject, it is easier to focus on what happens to the subject, i.e. the physical phenomena of solar energy entering the Earth's atmosphere or alternately being reflected back by it. In the former case, the greenhouse gases let the solar hero fly past freely, and in the latter case, the gases stop the hero by barring its course.

The anthropomorphised forms make recurrent appearances and become part of the character cast. This prevents the reader from getting confused; when the reader sees Harriet, the familiar single-celled organism, they immediately realize that the drawing is about the life and evolution of those same organisms, and that the creators are not trying to introduce a new topic or new organisms, which could easily be the interpretation if the character was any other than one of the previously seen organisms. Moreover, giving a recognizable visual form to the intangible elements or entities gives the creators a chance to show visually where the elements and things are situated in their environments. For instance, it is easy to notice that factory chimneys puff out $CO_2$ into the atmosphere because the smoke is drawn as the silhouettes of the $CO_2$ character (Klein & Bauman, 2014, p. 61). Moreover, the creators managed to bring a menacing feeling to the illustration by making the silhouettes black and the smoke clouds thick and a dominating feature in the image. A threatening image such as this evokes emotions in the reader, which in turn should lead to greater engagement with the comic. The anthropomorphised characters also evoke emotions of mirth: they are opportunities for humour, for instance, when non-human creatures act in human ways (Propp, 2009) – think of the single-celled organisms in domestic human activities, watching TV and pedaling an exercise bike – or through their facial expressions and body language – such as the $CO_2$ gas flexing its muscles in order to show its strength.

When it comes to the various nameless characters in CICC, many characters in the large cast are single-use and disappear after their first appearance, while others are introduced on one page and then reappear several pages later. Using both types of characters is an understandable decision from the part of the creators since the topics in the comic cover various different areas and fields and requires a versatile and flexible cast in order to progress the multi-faceted narration. Also, even though the topics are all connected through their link to climate change, making them all part of one great story featuring the same protagonist(s) might result in feeling forced. After all, the narration where a protagonist travels through time to the birth of the Earth and back again and across all continents has been seen many times before. And who would the protagonist be? No matter who it were, many readers would feel alienated and would find it difficult to relate to the protagonist.

Besides, including various nameless characters in different situations in lieu of one protagonist provides an opportunity to show how the lives of individual characters, separated from each other by time and distance, are affected by the changing climate, such as a photographer who notices that birds are migrating too early (Klein & Bauman, 2014, p. 73) or a gardener who is unable to hose their garden because they suddenly run out of water (p. 95). Since CICC is narration-driven, none of the characters are given names or backgrounds which would only limit their usage as generalizations, and they become vehicles for the narration. This fact enables turning the individual characters into generalizations: we see characters living their lives and dealing with their problems, but these individual characters represent larger populations or a larger group of people, for instance parents who have lost their child to a disease (Klein & Bauman, 2014, p. 109) or gardeners whose gardens are drying. The nameless characters are small and generalized but important and interconnected pieces in the story of Earth's changing climate.

Reappearances of characters work as reminders or humorous reunions. The scientists walk with the reader faithfully throughout the book, but some less important characters make one or several reappearances. These reappearances can occur within a spread or several chapters later. I assume that the purposes for the reappearances are, firstly, creating coherence in the book, and secondly, to remind the reader of, and make them recall, the theory and context where the characters appeared previously. Perhaps the characters work as visual prompts of previously learned theories that are quickly seen and processed in the reader's mind, and perhaps, if recalling is fast, memorizing the content and comprehending the links between theories become effortless and learning becomes more enjoyable. The reappearances can be examined from the point of view of emotions, too. The reader remembers seeing the character earlier in the book and feels a sense of familiarity. In some cases, it is useful to use characters who have appeared earlier and are able to evoke the sense of coherence and familiarity in the reader rather than use a new, completely random character. Characters' reappearances can be humorous, too, such as a cyclist and a driver who argue about the potential risks of climate change (Klein & Bauman, 2014, p. 84) and are later seen submerged under water, still on and in their respective vehicles and still shaking fists at each other (p. 93). In this case, the fact that the characters keep arguing, completely ignorant of their surroundings, is the source of amusement; also, as the rising sealevels are a result of climate change, by all logic their dispute should have been settled, but is not.

## 5. Discussion

The interview with Olivia Walch reveals traits from the artistic process of one science comic creator. Similarities can be found between Walch's working process and *The Cartoon Introduction to Climate Change* and also between Walch's working process and approaches to science communication, autonomous learning, and previous research on science comics. Walch routinely uses metaphors and analogies in order to make scientific facts and theories understandable. She also takes the audience carefully into account when designing her comics: this is visible in her choice of language and analogies. She pays attention to the readability and entertainment value of her comics and incorporates jokes and other diversions, such as GIF animations, in them in order to make the reading and learning experience lighter and more memorable.

*The Cartoon Introduction to Climate Change* adapts science content into a comic form in various ways and takes full advantage of the combination of the visual and the written verbal modes. The book's visual style, leaning towards abstraction, is both typical and atypical of other illustrations seen in other science texts. “Show and tell” is employed throughout the book: the written mode is dedicated for straightforward narration and description of phenomena, concepts, and scientific theories as well as sidenotes and humorous remarks from the characters while the visual mode is employed to show events, reactions, and objects. Narration is a significant part of the comic. The events and phenomena presented in the narration follow the flow of both everyday life and scientific recounts: events proceed in a temporally sequential order and include actors and objects as well as cause and effect. Descriptions of events and phenomena are interwoven into the narration, i.e. the characters of the comic participate in the events and explain and discuss the reasons and implications of events. The events and phenomena presented in *The Cartoon Introduction to Climate Change* are connected to real-life contexts in order to make learning and comprehension easier, for instance, the feedback loop that occurs during sound amplification is used as an analogue to feedback loops of climate. Similarly, using a coal-powered train that speeds ahead without a driver as a visual metaphor for the current reckless fossil-fuel–dependent lifestyle is an example of using contexts that are familiar to the audience.

The creators of *The Cartoon Introduction to Climate Change* have taken the audience into account by paying attention to the language and vocabulary used in the book, by using metaphors and real-life contexts that are familiar and interpretable to the audience, and by generally adhering to the conventions of comics and science texts. Extraneous, unnecessary details are omitted from the comic, for instance by revealing or bringing attention to exact figures only when necessary. The

language of the comic book is colloquial: it is more narrating and conversational than didactic, and scientific terms are often replaced with colloquial or shorter terms.

In addition to education, *The Cartoon Introduction to Climate Change* aims to entertain and amuse its audience as well as to motivate it to continue reading, by incorporating verbal and visual jokes either in the midst of narration or in characters' actions. Moreover, *The Cartoon Introduction to Climate Change* provides emotional stimulation; for instance, the reader may feel pity for animals whose habitats are currently disappearing or have already been destroyed because of human activity. The jokes and sources of emotional stimulation are, I think, quite universally understood – or, if the reader does not understand them, they are at least able to come up with an explanation of their own –, and that adds to the appeal of this comic book.

Characters both help at comprehending the science content and entertain. As the scientist characters in *The Cartoon Introduction to Climate Change* often speak directly to the reader, it could be said that the reader becomes actively involved in the events in the comic. The reader is represented by various child characters: the children react in ways that are assumed or expected of the reader, such as ask questions of the scientists, investigate the reasons for climate change, and start to act to prevent further harms of climate change. As can be seen from these examples, the characters are usually not characters in the traditional sense of the concept; the human characters do not represent a single individual, such as a Peggy who goes to a laboratory to talk to scientists and learn about climate change, but larger groups of people which is only emphasized by the characters' namelessness and uniform appearance. Such impersonalization might create a distant tone in the narration, but that is avoided through the usage of light-hearted humour and by evoking emotions, such as empathy or dread, in the reader. On the other hand, some characters become very personal: in *The Cartoon Introduction to Climate Change*, personification has been used abundantly, and things such as energy (solar energy, energy emitted by Earth, etc.) and single-celled organisms have been given faces and names, and they speak and act in human-like ways.

Considering all this, it could be said that *The Cartoon Introduction to Climate Change* is a science comic that combines science communication and entertainment in ways that are appropriate for informal learning. The comic strives to inform the reader about climate change and communicate the big picture of the phenomenon without feeding the reader extraneous trivia. Thus, the book is probably a functional learning material for many kinds of readers who wish to enlighten themselves on the topic, especially those who cannot or will not read traditional books. However, even though science comics may be an answer to some people who struggle with reading or do not want to read linear text, they may be a step in the wrong direction for others. For instance, a family

member of mine argues that not being able to understand the topics from pictures alone irritates them about *The Cartoon Introduction to Climate Change*, and that having to read so much text in a comic confuses them; in this case, I assume that inexperience in reading comics is the main reason for them rejecting the comic book. Moreover, some dyslexic people find any kind of reading such an insuperable barrier that they prefer audio books in all situations. These examples alone show that we humans are all individuals when it comes to learning and even entertainment. When possible, each pupil and student should be given a chance to choose their own learning tools so that their learning is as effective as possible.

Effectivity, however, should not be the only measure of the quality of a learning experience. Animations, jokes, and other kinds of disractions from and additions to science content increase the quality of the educational experience, but is that the only value of entertainment in education – that it improves learning results? Does it not have a value of its own? Could we see the worth of science comics and entertaining media per se even if the learning results they produce are equal to that of a traditional textbook? Ecology of learning emphasizes the quality of learning instead of standardised learning results, so it could be said that if a reader finds a science comic more engaging than a text book, their reading and learning experience has a better quality than without the feeling of engagement whether the entertainment increases their understanding of science content or not. Sure, learning is not always supposed to be fun, but when possible and appropriate, why not make it fun and choose a science comic instead of a textbook? Of course, we are walking a fine line here: it is easy to slip over the edge where entertainment turns into distraction; also, it has been mentioned that science comics create a sense of false understanding and that science comics may be more beneficial for beginner students than advanced students, just like *The Cartoon Introduction to Climate Change* is namely an introduction to the topic of climate change. These are all factors that should be considered carefully when designing the content of a curriculum or learning material.

That does not mean that comics are unusable in expert environments, however. As has been discussed, science comics are useful not only for students and pupils but professionals as well: accessible and comprehensible science communication is important when sharing ideas in scientific communities (McDermott, Partridge, & Bromberg, 2018), and the same can be assumed to apply to working environments where professionals from different fields and disciplines meet. Communicating their ideas and perspectives as well as the basic principles of their respective fields clearly and effectively becomes crucial in these environments. In the Western world, comics have long been regarded as kids' entertainment or light entertainment; however, this is changing, and perhaps researchers themselves using comics for communicational purposes and as learning tools in academic settings might be what the medium needs in order to be finally taken seriously.

## 6. Conclusion

The focus on an alternative learning tool makes this study important in a wider social context. Especially at a time when the individual needs of students are being acknowledged and learning – even in settings of formal education – is no longer focused on simply reading traditional text books, it is worthwhile to consider different educational tools that can contribute to successful education. Moreover, research on all kinds of media and their uses for autonomous learning deserves attention because learning occurs in all places and at all times, not only in schools. It is in the best interests of various parties – students, parents, governments, trade and industry, teachers, educational establishments and institutions – to produce long-lasting learning results efficiently. This thesis gives insight into the ways a science comic both educates and entertains its readers and may provide an analytical basis for future studies. Hopefully, this study will also encourage creators of science comics to reflect on their own creative processes, and perhaps the findings give first-time creators rough guidelines to planning a science comic.

Future research of the topic could include investigating comics as learning tools in Finnish settings. Investigating how comics can be integrated in both teaching and autonomous learning in different educational levels and contexts would be beneficial on a national level and would hopefully produce results that are directly applicable in the Finnish educational system, thus benefitting Finnish pupils, students, teachers, and researchers. Another direction of research is to study to whom using comics in education would be the most beneficial – students with learning disabilities, so called "low-achievers", beginner classes, primary school pupils, college students, etc. Relating to this, investigating which fields and subjects are the most fruitful areas for the employment of educational comics is another area of interest. The durability of learning results as opposed to other learning tools, such as traditional textbooks, is yet another intriguing research topic. A rather different direction would be to study the use and effectiveness of educational and informational comics in working environments.

Researchers and scientists make comics because the creative process improves their thinking (McDermott, Partridge, & Bromberg, 2018), so another direction for future research is studying comics as homework or other assignments and how these kinds of assignments affect learning. The research could be applied to both formal and informal learning settings in many school subjects. Another interesting research direction concerns the production and/or usage of educational comics and would probably take advantage of ethnographic or autoethnographic methods, either by studying the working processes of comic creators or the learning processes of students.

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## Appendices

### Appendix A

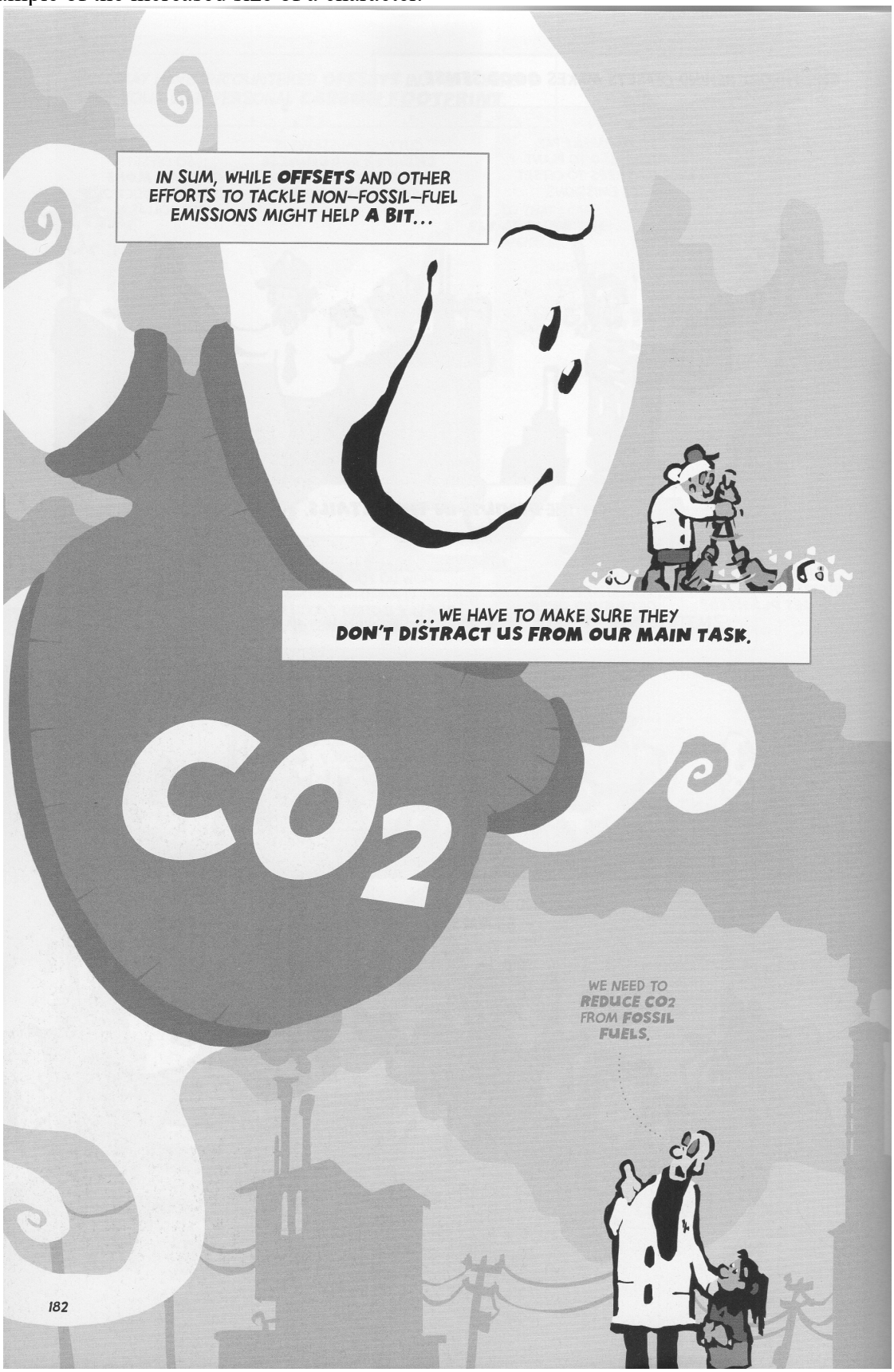
Questions to Olivia Walch.

*[Initial questions]*
1. What kinds of science comics have you made? Topics?
2. How did you start making science comics?
3. How did you learn to make science comics?
4. How do you choose topics for your science comics?
5. Tell us about the process of making a science comic. (You can use a comic you've made as an example.) Example questions:
    - How do you adapt scientific facts and theories to a visual form?
    - Audience – who is your audience? How do you take your audience into account? How do you make sure people from different backgrounds understand the science in the comic?
    - Where and when are your science comics read? How do you take this into account when planning and making the comic?
    - How do you make your science comics entertaining?

*[Further questions]*
6. How do you incorporate humour in science comcis? - e.g. do you script jokes etc. for the comics, or do you make them up as you draw?
7. What kind of humour do you prefer to use in your comics? E.g. verbal jokes, visual jokes, sitcom-type humour... (You can use examples again)
8. What kind of feedback have you received regarding humour and entertainment value in your science comics?
9. In your opinion, how important are humour and entertainment in science comics? Is entertainment an integral part of science comics, or can you do without? How do you think it changes the reading and learning experience if a science comic is purely informational and not at all entertaining?

**Appendix B**

An example of the increased size of a character.



**Appendix C**

An visualization of different energies and their reactions with greenhouse gases.